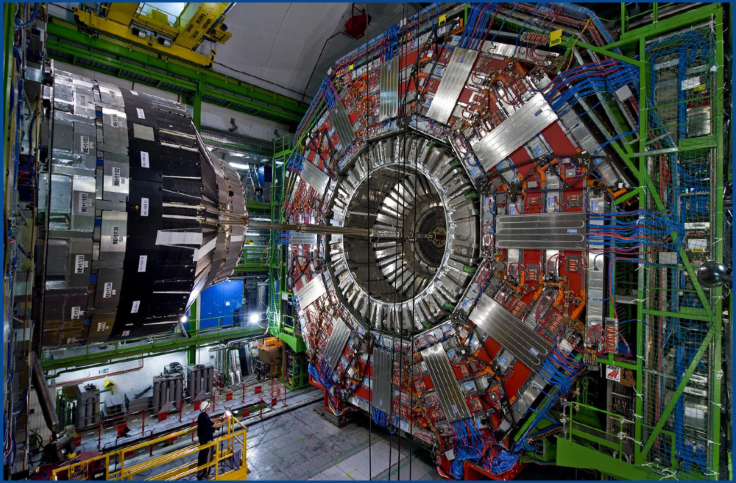
Highlights and Perspectives from the CMS Experiment

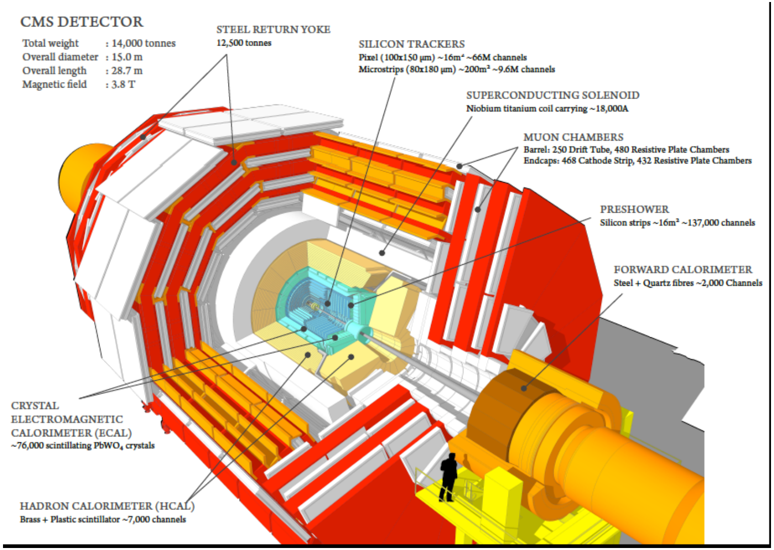


Joel Butler
Talk Presented to LHCP 2017
Shanghai, China
May 15, 2017

Outline

- LHC and CMS Performance in 2016
- Recent Physics Results
  - Measurements, a.k.a. Precision Frontier
  - Searches, a.k.a. Discovery Frontier
- Prospects for Run 2
- The Future: HL-LHC Upgrade
- Summary and Outlook

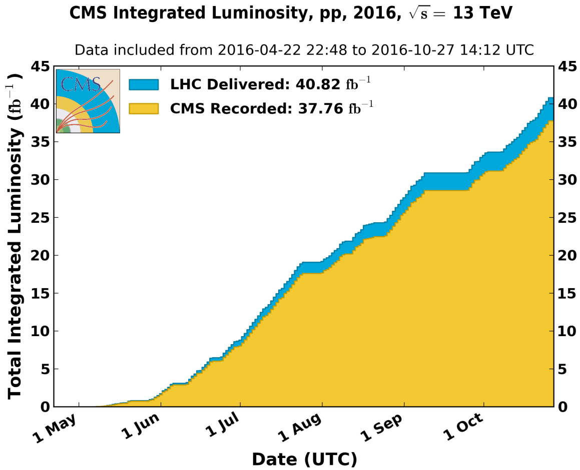
CMS Performance in 2016



CMS in 2016

- New Capabilities
  - Forward Proton tagging
    - CMS Totem – Precision Proton Spectrometer CT-PPS
      - Tags forward protons to identify double diffractive scattering and Central Exclusive Production of high mass states
  - New Level 1 Muon trigger
  - New Level 1 Calorimeter trigger
  - Endcap Muon Detectors had been upgraded in 2013/14
- Cryogenic System (a.k.a. COLD BOX) for CMS solenoid performed superbly
  - Repair/refurbishment plan succeeded to avoid problems encountered in 2015
- **Big challenge – to deal with even higher pileup than Run 1**

LHC and CMS Performance in 2016

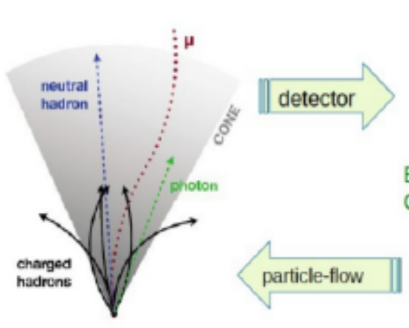


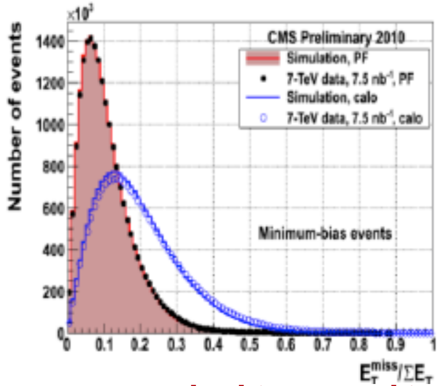
- LHC has exceeded DESIGN Luminosity
  - 2016 maximum peak lumi 1.5×10^{34} cm^{-2} s^{-1} with pileup ~ 45
    - With 2208 colliding bunches
- LHC has much higher availability, ~50%, than expected
- CMS recording efficiency held steady at 92.5%
- Each CMS sub- detector had >96% of all channels working

Data validated for all detectors is ~95% of the data recorded ➔**35.9 fb^{-1} to analyze**

Original goal for 2016 was 25 fb^{-1}

Particle Flow Technique





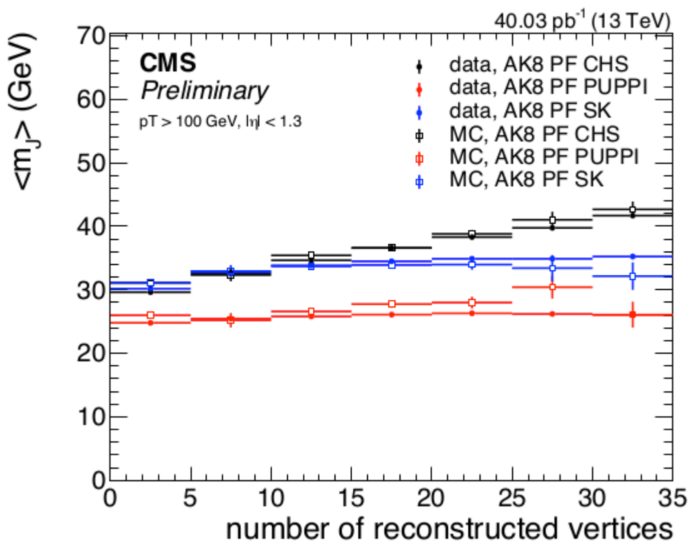
- **Information from all detectors used optimally to reconstruct each object, tracking is used together with calorimetry to reconstruct showers, jets, etc**
- Particles are well-separated in the huge tracker volume and the 3.8T magnetic field
- CMS has an all silicon tracker out to 1 m radius, giving excellent track resolution and coverage, able to go down to very low momenta (~a few hundred MeV)
- The electromagnetic calorimeter has excellent resolution and high granularity
- In jet events, only 10% of the energy comes from neutral hadrons that can only be measured using the hadron calorimeter

Particle Flow produces a big improvement in jet energy resolution, Tau identification, and helps with high pileup

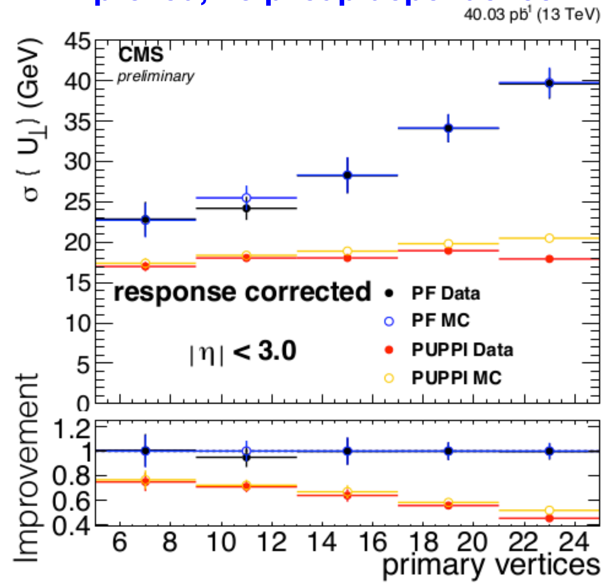
Object Performance at High Pileup
PileUp Per Particle Identification (PUPPI)

- Basic idea: weight particle momenta according to the probability of not having pileup activity around it (based on the sum($p_T/\Delta R$) shape)

Jet mass independent of pileup and intrinsically "groomed"



Missing transverse momentum resolution improved, no pileup dependence

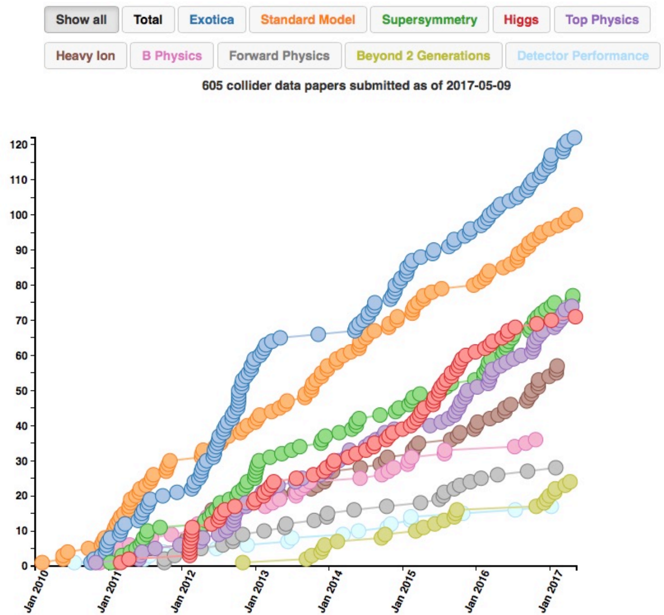


Physics Results

Publication Status

605 physics papers submitted

- http://cms-results.web.cern.ch/cms-results/public-results/publications-vs-time/



39 new results released for Moriond 2017 conferences

- http://cms.cern/news/cms-new-results-Moriond-2017

CMS Results in Moriond and LHCP

Many results use full 13 TeV dataset recorded in 2016: 35.9 fb^{-1}.

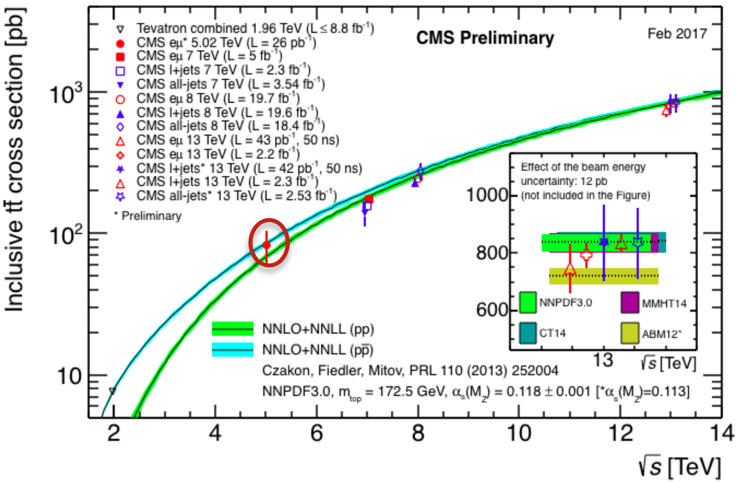
Many new results since Moriond

- **Higgs**
  - Mass in 4l
  - fiducial cross section in 4l and di-photon
  - Higgs coupling in ttH
  - Search for (non-)resonant HH
- **Top, Electroweak, and QCD**
  - (Differential) cross section in ZZ, Z+jj, ttbar
  - Inclusive spectra of very forward jets using also CASTOR
  - Anomalous triple gauge coupling
  - 2-jet and 3-jet azimuthal correlation
  - New top mass in lepton+jets and tt+W/Z cross section
- **B Physics :** P5’ in K*mumu and B lifetime
- **Exotic searches**
  - Heavy resonances, di-bosons and boosted object, vector-like quark
  - X + MET: jet, hadronic V, Z(ll), H(γγ)
  - Long-lived particles
- **SUSY:** comprehensive campaign from inclusive hadronic to electroweakinos

Precision Frontier

Solving the mystery using circumstantial evidence

Top Pair Cross Sections



Factory	Quark	Cross Section (nb)	Luminosity ($cm^{-2}s^{-1}$)
B (KEKb)	Bottom	1.15 (Υ(4S))	2.11×10^{34}
LHC	Top	0.82 (incl t-t)	1.51×10^{34}

CMS: 835 ± 33 pb
Theory: 816 ± 42 pb

Top pair rate is > 10 Hz, enabling us to address much more precise questions

- Single and double differential cross sections
- Rare (FCNC) decays
- CP violation (a beginning)
- Width and more complex methods for measuring the mass

Top pair production at 13 TeV CM energy is mainly (80%) produced by gluons, providing important information on the gluon distribution at relatively high x_F, up to ~0.25

CP Violation and Rare Top Decays (Run 1)

TOP-16-001, JHEP 03 (2017) 101

- First search for asymmetry in T-odd triple vector products. Top in lepton (t vs tbar tag) plus jets.

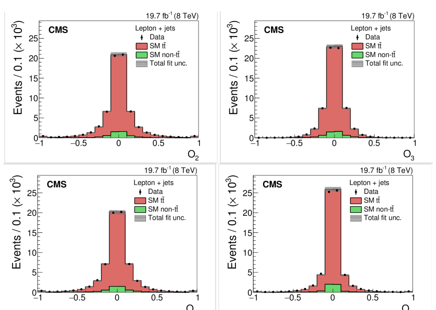
$$A_{CP}(O_i) = \frac{N_{events}(O_i > 0) - N_{events}(O_i < 0)}{N_{events}(O_i > 0) + N_{events}(O_i < 0)}.$$

$$O_2 = \epsilon(P, p_b + p_{\bar{b}}, p_\ell, p_{j_1}) \longrightarrow \propto (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1}),$$

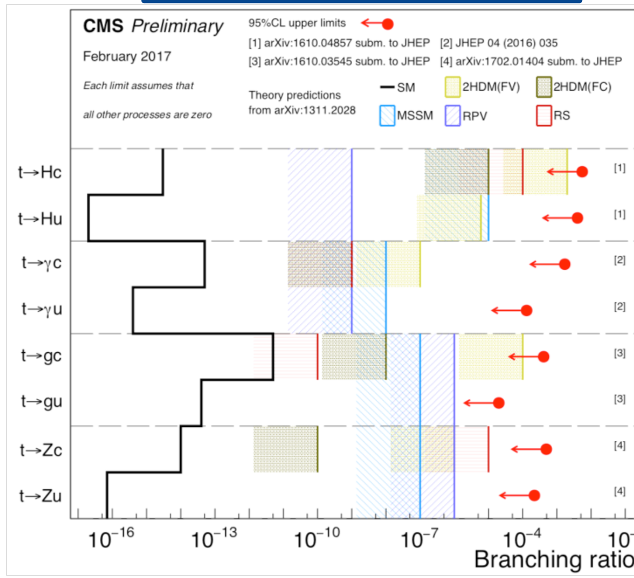
$$O_3 = Q_\ell\, \epsilon(p_b, p_{\bar{b}}, p_\ell, p_{j_1}) \xrightarrow{b\bar{b}\mathrm{CM}} \propto Q_\ell\, \vec{p}_b \cdot (\vec{p}_\ell \times \vec{p}_{j_1}),$$

$$O_4 = Q_\ell\, \epsilon(P, p_b - p_{\bar{b}}, p_\ell, p_{j_1}) \xrightarrow{\mathrm{lab}} \propto Q_\ell\, (\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j_1}),$$

$$O_7 = q \cdot (p_b - p_{\bar{b}})\, \epsilon(P, q, p_b, p_{\bar{b}}) \xrightarrow{\mathrm{lab}} \propto (\vec{p}_b - \vec{p}_{\bar{b}})_z (\vec{p}_b \times \vec{p}_{\bar{b}})_z.$$



Rare, FC Top Decays



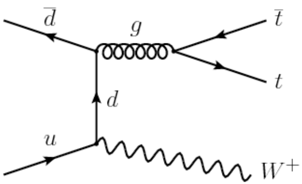
First Run 2 results will appear soon. None will reach SM expectations but some will reach level predicted by some BSM models

Top production with additional objects – ttW and ttZ

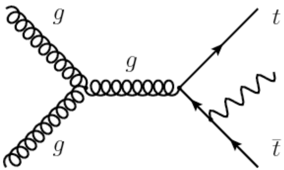
Coupling of Top to Z boson and a direct measurement of a significant background to many searches

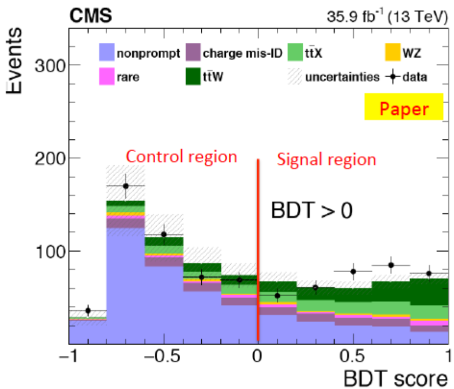
TOP-17-005

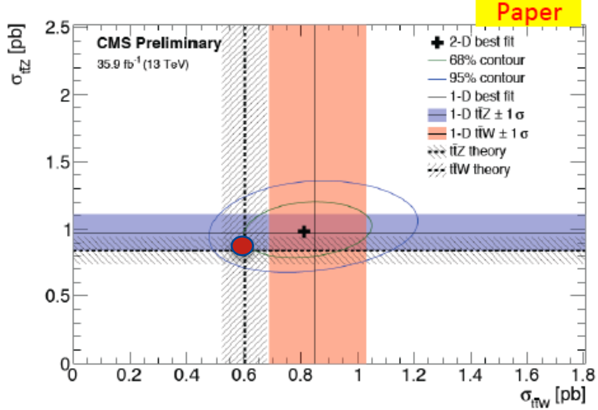
Same sign di-lepton



3, 4 leptons





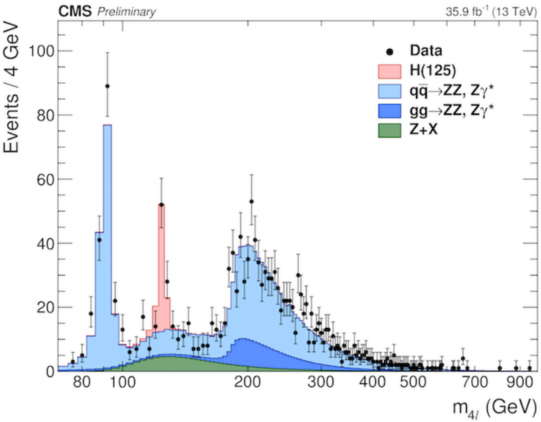


Significance :	ttW^-	ttW^+	ttW
Expected:	2.4σ	4.3σ	4.7σ
Observed:	2.5σ	5.9σ	5.9σ

Measured ttV signal strength:

$$r(t\bar{t}W) = 1.22\ ^{+0.08}_{-0.09}(\text{stat.})\ ^{+0.11}_{-0.13}(\text{sys.})$$

Higgs Properties from ZZ* (4 leptons)

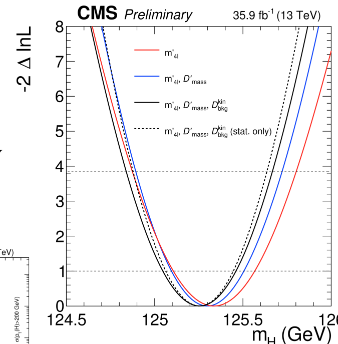


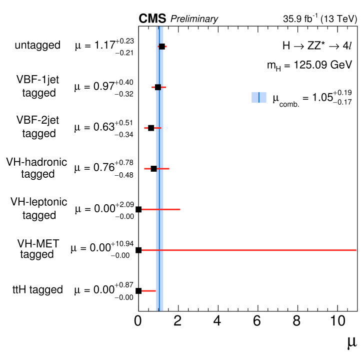
ATLAS, CMS Run 1 Combined:

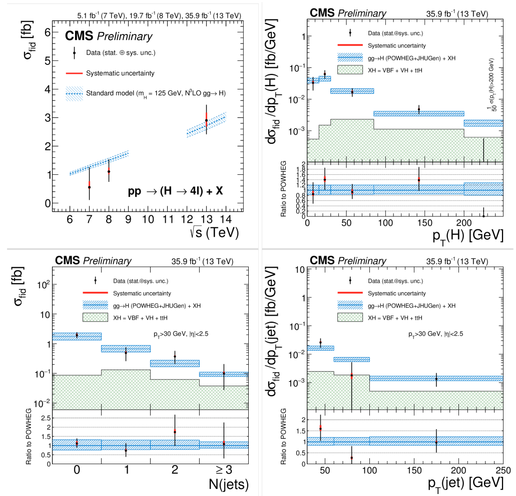
$$M_H = 125.09 \pm 0.21(stat) \pm 0.11(syst)\ GeV$$

CMS 2016, 4 lepton:

$$M_H = 125.26 \pm 0.20(stat) \pm 0.08(syst)\ GeV$$





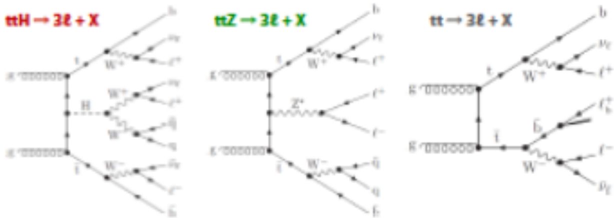


HIG-16-041

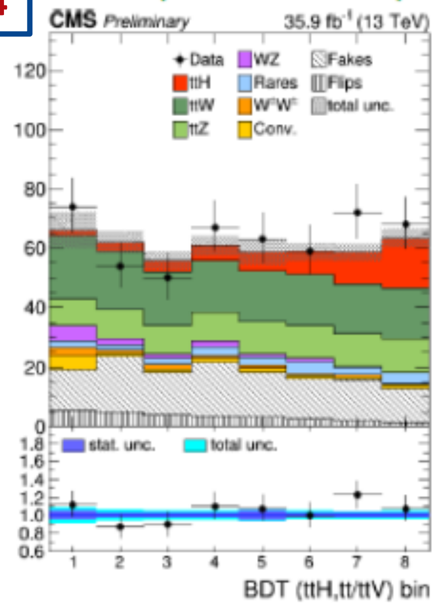
Cross sections

Higgs Coupling to Top Quarks

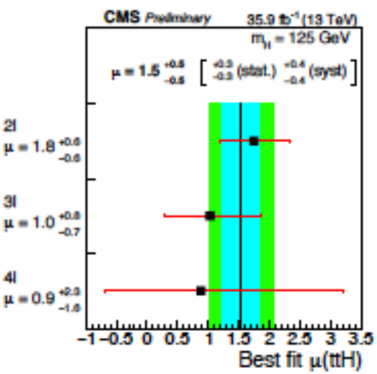
HIG-17-004

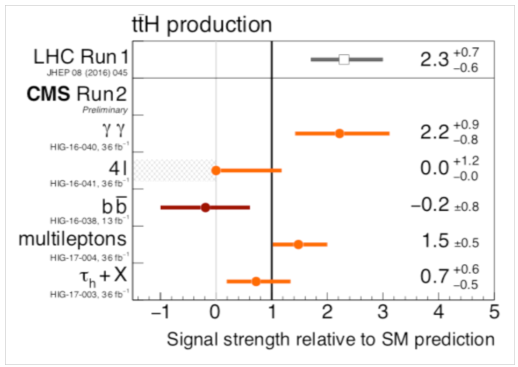


SR bins (all cat. combined)



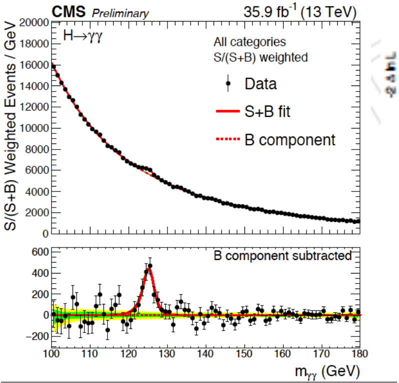
SS dilepton

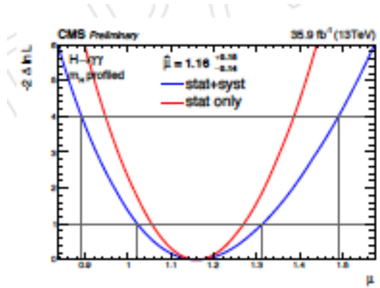




3σ evidence for tt-H in multi-lepton final states
3.3 σ (2.5 expected) when combined with 2015 result

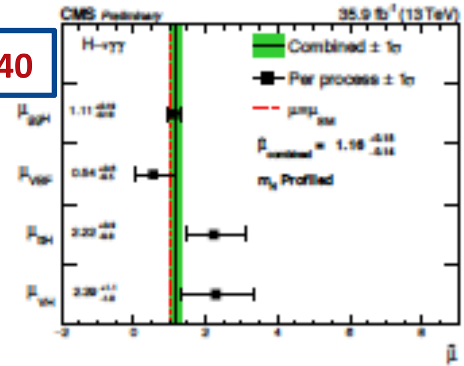
Higgs → γγ



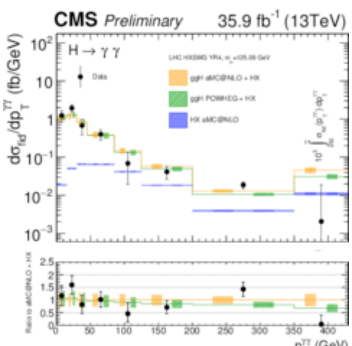


Likelihood scan for signal strength

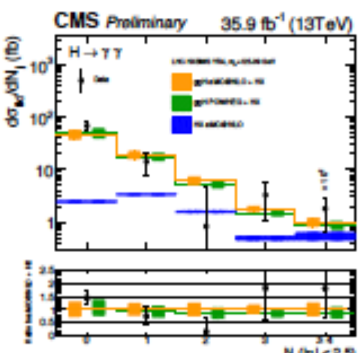
HIG-16-040



Signal strength modifiers



Differential cross section



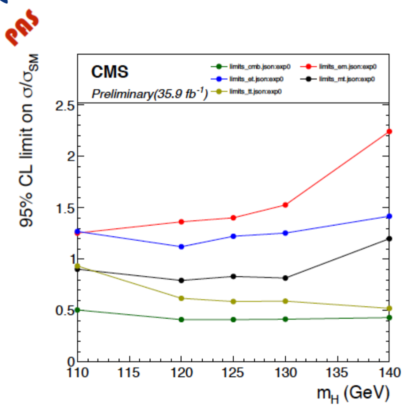
Njet Differential cross section

HIG-17-015

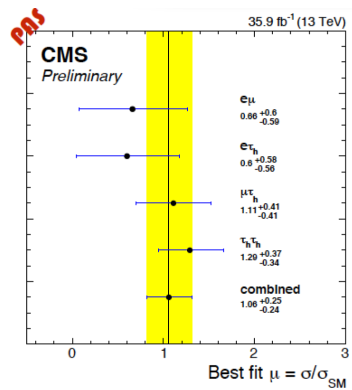
Higgs →$\tau^+\tau^-$

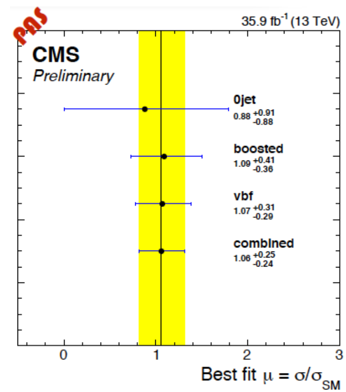
HIG-16-043

- Four decay topologies for $\tau^+\tau^-$: eμ, eτ_h,$\mu\tau_h$,$\tau_h\tau_h$
- Three production modes: 0-jet (gg), VBF, boosted (additional objects)
- Irreducible sources of systematics: W+jets, DY Z/γ →ll,$\tau\tau$, t-tbar, QCD



$\tau^+\tau^-$, $\mu\tau$ most sensitive



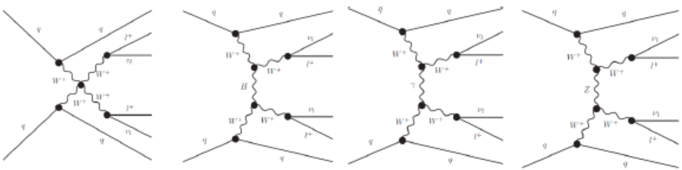


μ(signal strength)= 1.06 +0.25-0.24

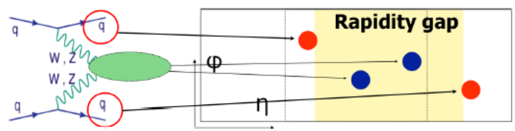
Significance 4.9 σ; CMS combined will be > 5 σ

WW Scattering using Two Same-sign Leptons and Two Jets

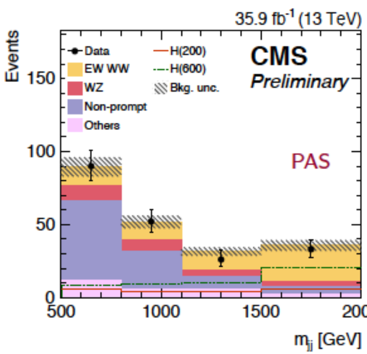
Addresses nature of Higgs, which helps unitarize $V_L V_L \rightarrow V_L V_L$ and provides a search for doubly charged Higgs

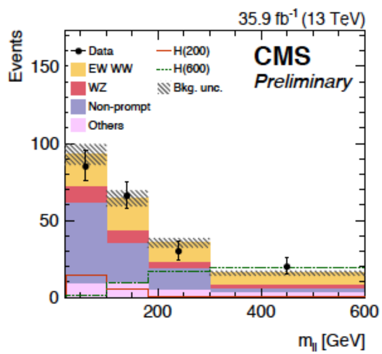


$W^{\pm}W^{\pm}$ scattering in the fully leptonic final state



SMP-17-004





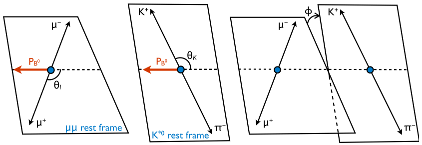
charged H x-sec $= 0.1pb$

Observed (Expected) signficance: 5.5 (5.7) σ

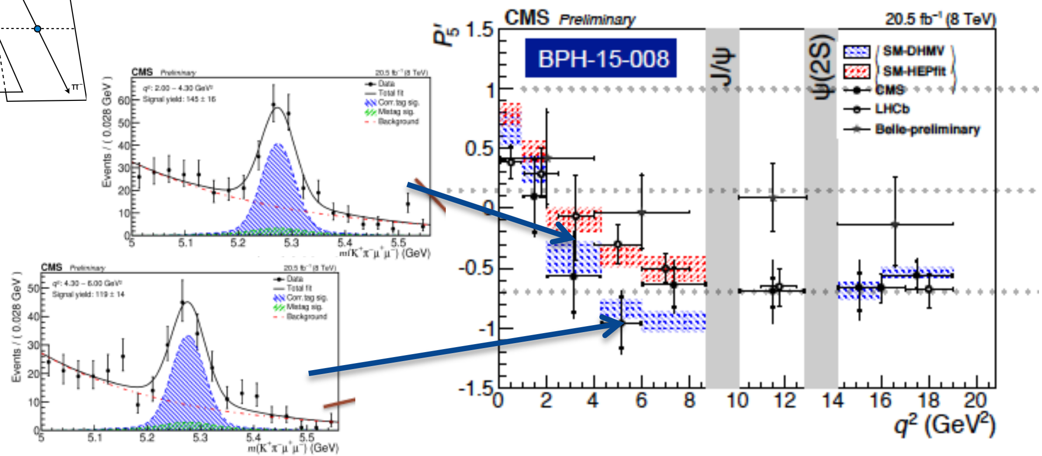
Observed signal strength relative to SM prediction: 0.90 ± 0.22

$\sigma_{fiducial} = 3.83 \pm 0.66(stat) \pm 0.35(syst) \pm 0.12(Lumi)\, fb$

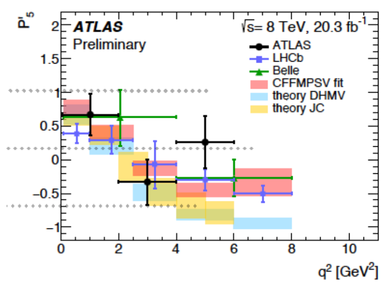
P5′ in $B^0 \rightarrow K^{*0}\mu^+\mu^-$ (8 TeV)



BPH-15-008

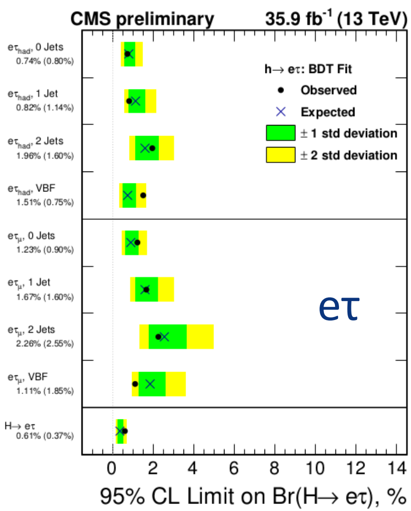


$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_K\, d\phi} = \frac{9}{8\pi}\left\{\frac{2}{3}\left[(F_S + A_S\cos\theta_K)(1-\cos^2\theta_l) + A_S^5\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right] + (1-F_S)\left[2F_L\cos^2\theta_K(1-\cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{1}{2}P_1(1-F_L)(1-\cos^2\theta_K)(1-\cos^2\theta_l)\cos 2\phi + 2P_5'\cos\theta_K\sqrt{F_L(1-F_L)}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right]\right\}. \quad (1)$$



Rare Decay Highlight

- **Search for lepton flavour violating decays of the Higgs boson to eτ and μτ in proton-proton collisions at 13 TeV with full 2016 statistics.**
  - Previous 2.4σ hint in H→μτ in Run1 data (*Phys. Lett. B* **749** (2015) 337) not confirmed
  - stringent limits set on branching fractions, well below 1



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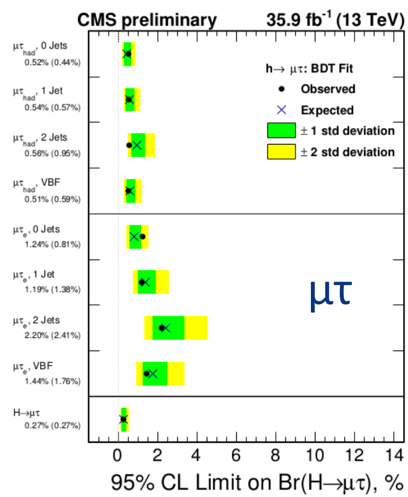


Searches

Solving the mystery by finding an eyewitness or getting it on video

Supersymmetry

Retrospective:
- Great theory – could solve three problems at once
- In 2010, many thought SUSY would be seen soon after startup- 100 pb^{-1}
- **Expected to be first major LHC discovery– before even the Higgs**

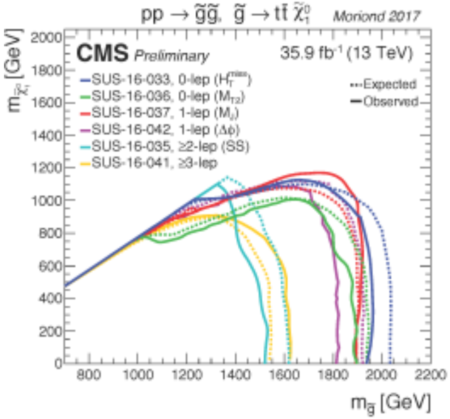
Reality at start of 2017 run: So far, SUSY is a "no show". Why?
- Maybe heavier than we thought
- Maybe more devious/obscure than we thought
  - But many considerations of stealth SUSY, compressed spectra etc., now considered and did not work out, at least yet
- Maybe it does not cure all
  - Coverage for RP-violating and long-lived particles not as complete
- Maybe just another great idea that nature did not choose to follow

SUSY Searches

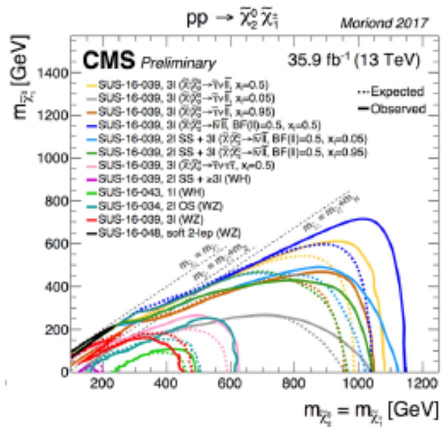
Broad program: 19 searches completed with full 2016 CMS dataset, with several already submitted to journals

- Probing different models (inclusive production, strong and electroweak production, and 3rd generation sparticles (stops)
- Different final states(with leptons, photons, jets) and analysis techniques

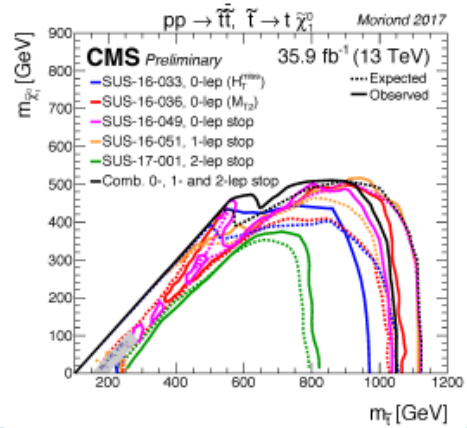
gluinos (inclusive)



electroweakinos



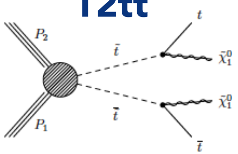
stops (3rd gen)



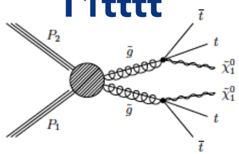
New result on STOP and gluinos

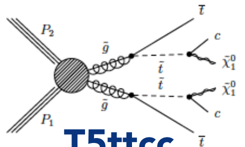
- Search for decay chains with two or four top quarks in the final state.
  - STOP decays to top and LSP
  - gluinos are produced and decay through a top and a virtual stop going to top and LSP and
  - Gluinos are produced and decay through a top and a real stop going to charm and LSP
- Special techniques are developed to identify multiple hadronically-decaying top quarks over a large range of P_T. Both boosted and resolved jet reconstruction is used.

T2tt



T1tttt

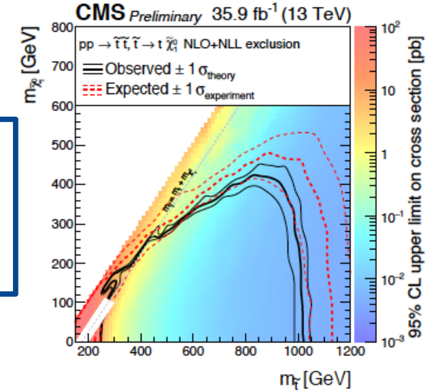




T5ttcc

SUS-16-050

STOPS are ruled out at 95% CL up to ~1TeV for neutralino/LSP less than about 430 GeV

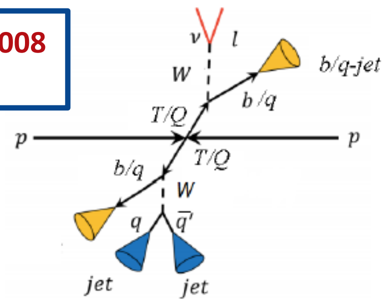


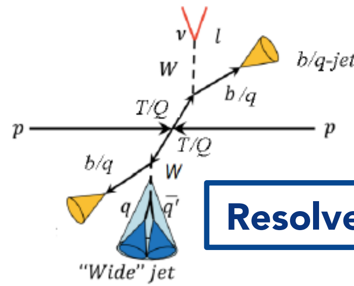
Boosted Objects, e.g., Vector Like Quarks

B2G-17-003

See B2G-17-008
For Q=5/3

$$T\bar{T} \to bW^{+}\bar{b}W^{-} \to b\ell\nu\bar{b}q\bar{q}'$$,Q=2/3



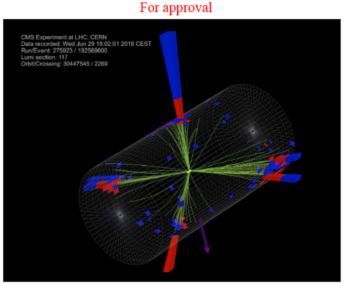


Resolve into two subjets

AK8 jets

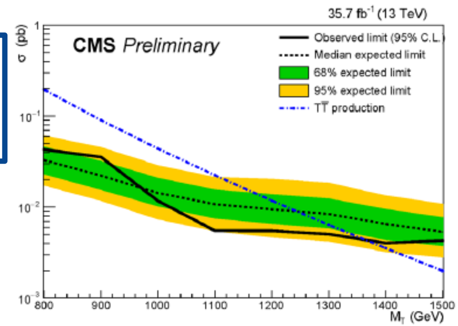
High mass event

For approval



4 May 2017 B2G-17-003 approval 48

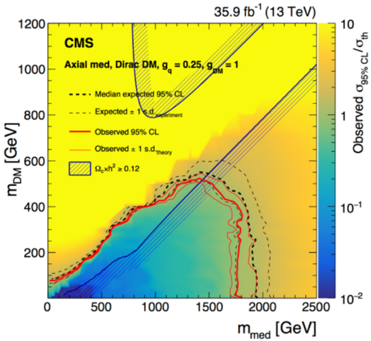
Limit:
Expected: 1245 GeV
Observed: 1365 GeV

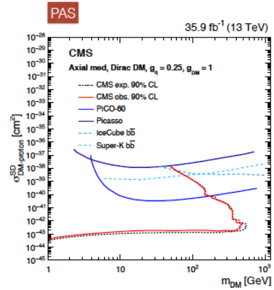


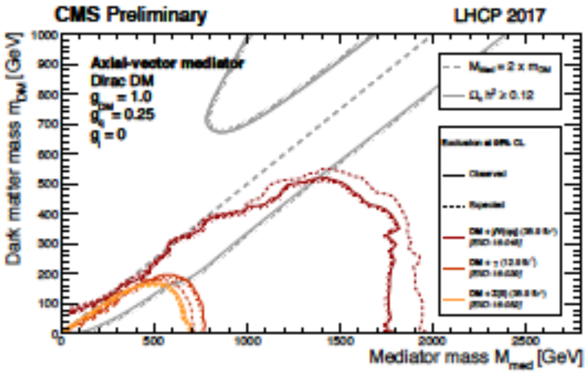
Dark Matter

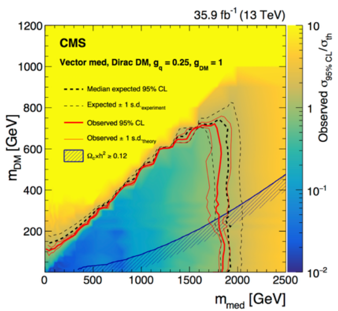
Mono-jet and mono-V(W,Z) search with full 2016 dataset. Limits on Simplified models of DM and several other topics.

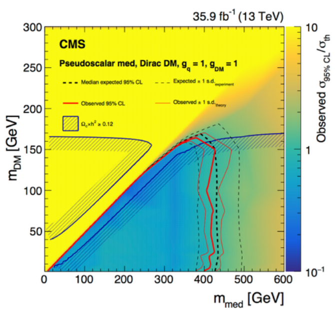
EXO-16-048







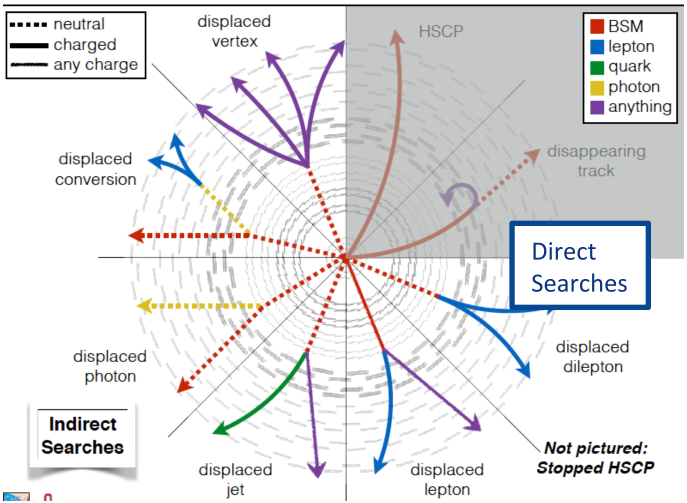




95% CL observed/expected exclusion regions for MET-based DM searches in the lepto-phobic Axial vector model.

Long-Lived Particles

Many BSM models have long-lived particles /displaced vertices. Some of these can be observed by special searches, usually with special triggers

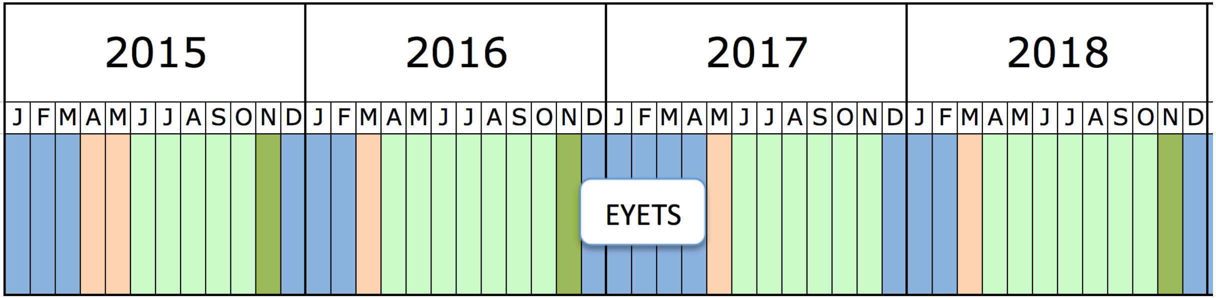


EXO-16-004

- Search for stopped long-lived particles using full 2015 and 2016 data
  - Signature is a high energy jet in the calorimeter out of time with collisions
  - gluinos with lifetimes from 10 μs to 1000s and m_{gluino} < 1379 GeV are excluded.
  - Top squarks with lifetimes from 10 μs to 1000s and m_{stop} < 740 GeV are excluded

Status of CMS for 2017 Run

Run 2 Schedule



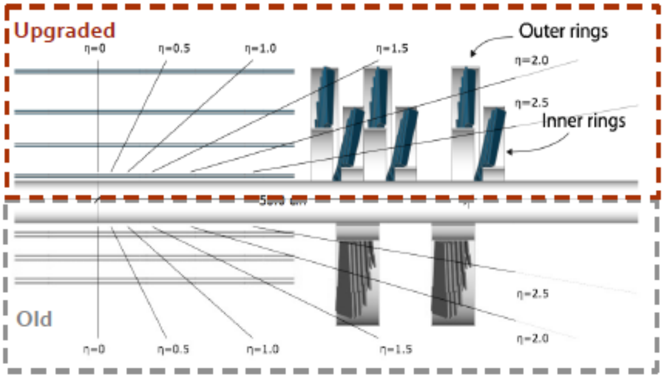
Shutdown/Technical stop
Protons physics
Commissioning
Ions

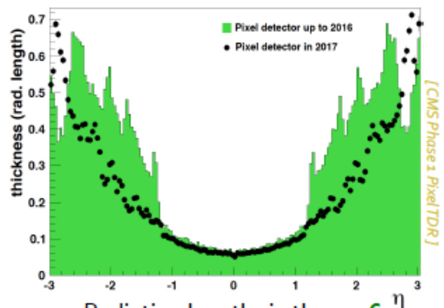
- Peak luminosity "soft" limit is **~1.7e34** from inner triplets
- ~40 -50 fb^{-1}/year in 2017/18 so > 100 fb^{-1} Run 2

Current status and plans

- CMS detector is closed
- Solenoid is cold and is operating at 3.8 T
- Running regularly on cosmics with magnet off (CRUZET) and on (CRAFT) and all detectors reading out, including Pixels
- Ready for collisions (some work on pixels with first collisions)

Phase 1 Pixel Detector Installed for 2017 Run





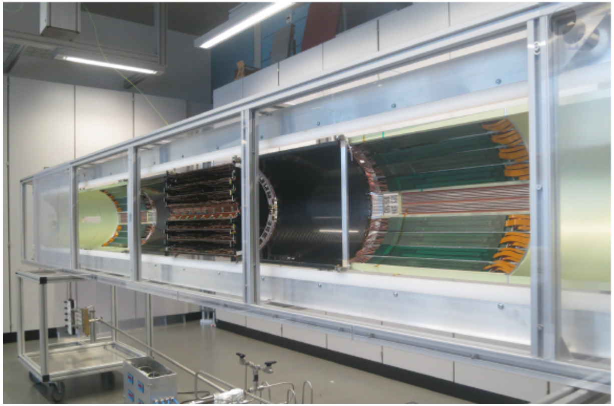
Radiation lengths in the **2016** and **2017** pixel detectors

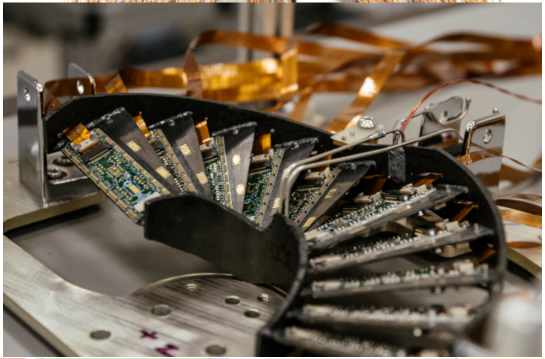
Pixel Upgrade: **(Installed !!!)**

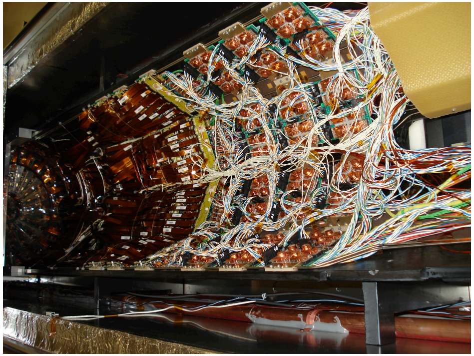
- Baseline L = 2×10^{34} $cm^{-2} sec^{-1}$ with 25ns BX → 50 pileup **(50PU) with very small efficiency loss**
- **More Robust tracking** : 4 hit coverage; **3 layers/2 disks to 4 layers / 3 disks** (can compensate point losses in strips)
- **Better readout able to run up to 2-2.5x10^{34} cm^{-2} s^{-1} with almost no inefficiency (from hit loss) or dead time and radiation hard enough to survive Integrated Luminosity of 500 fb^{-1}**
- **Much less material in front of outer Tracker**
- Inner layer closer to beam → Better primary and secondary vertex resolution

Pixels

BPIX (outer): L1, L2, L3 & L4 merged





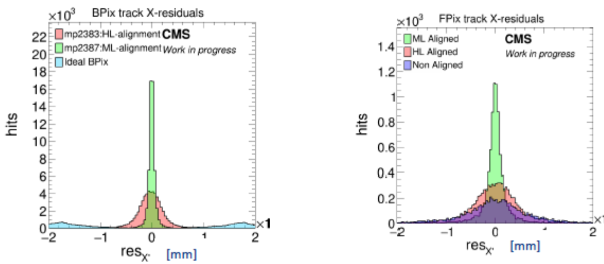


Other Changes to CMS for 2017 Run

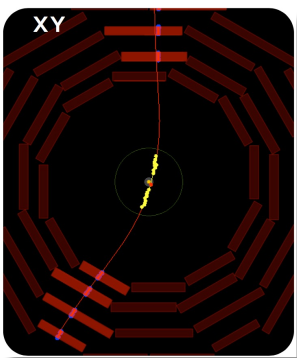
- In addition to the highest priority effort to install the new pixel detector
  - Implement multi-anode feature of PMTs on Forward Hadron Calorimeter (HF) to Reject spurious signals that produce false MET
  - GEM (Gaseous Electron Multiplier)-based muon detector slice in Endcap
    - First use of technology needed for HL-LHC
  - Luminosity monitor replacement and upgrade
  - Forward proton spectrometer now has precision timing detectors

Cosmic Runs and First Collisions

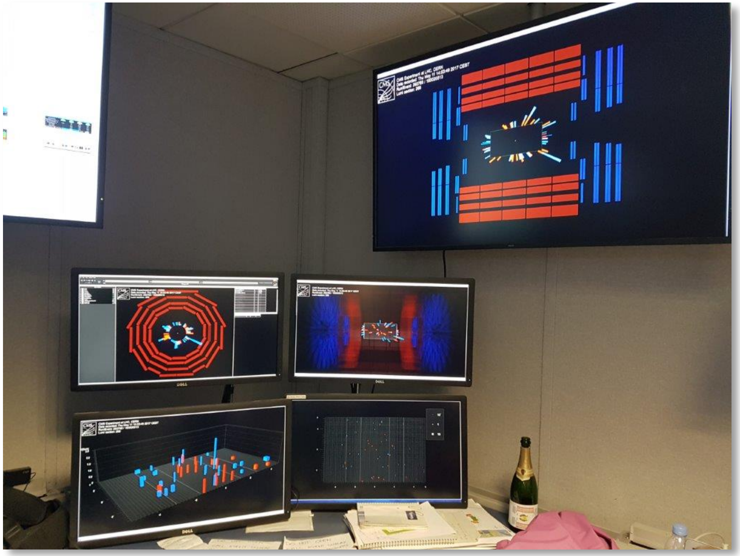
Pixel Alignment to 50-100 μm in Cosmic Run at 0T



Cosmic Run at 3.8T



- We got our first 2017 (test) collisions on May 11 at 3pm !!



* CMS does not turn trackers on until LHC declares "Stable beams"

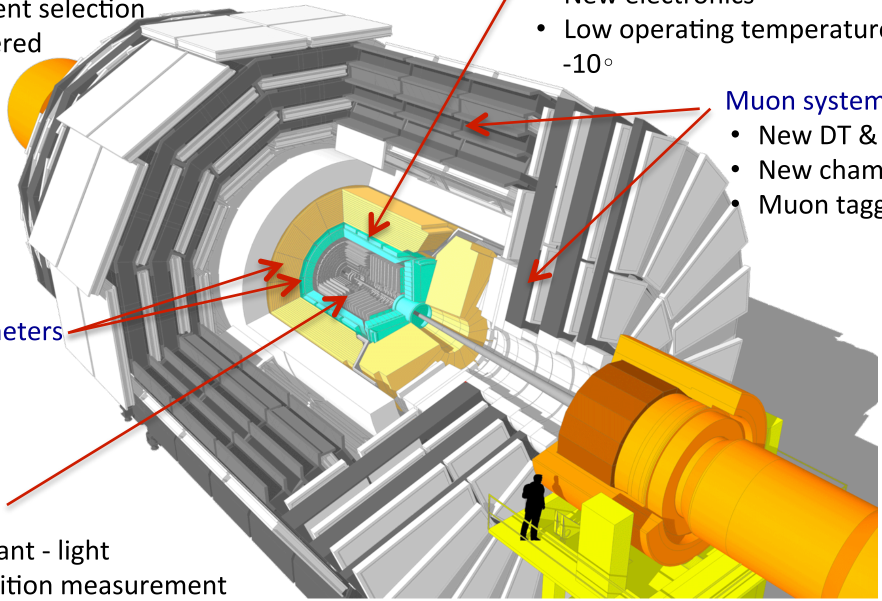
The Future: CMS HL-LHC Upgrade

CMS Phase-II upgrades

Technical proposal CERN-LHCC-2015-010 https://cds.cern.ch/record/2020886
Scope Document CERN-LHCC-2015-019 https://cds.cern.ch/record/2055167/files/LHCC-G-165.pdf

Trigger/HLT/DAQ

- Track information in hardware event selection
- 750 kHz hardware event selection
- 7.5 kHz events registered



Barrel EM calorimeter

- New electronics
- Low operating temperature ≃ -10◦

Muon systems

- New DT & CSC electronics
- New chambers 1.6 < η < 2.4
- Muon tagging 2.4 < η < 3

New Endcap Calorimeters

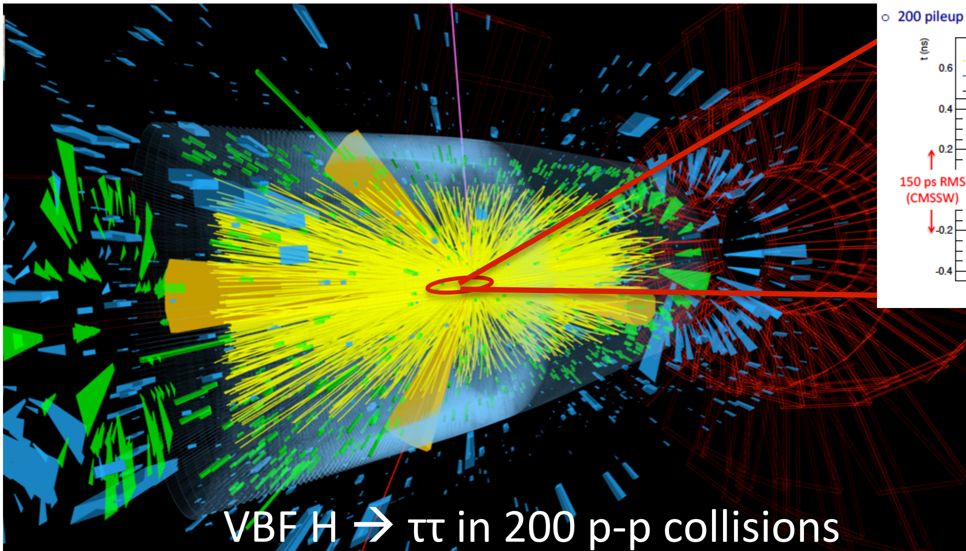
- Rad. Tolerant
- 5D measurement

New Tracker

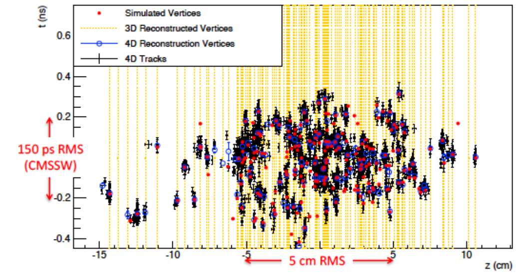
- Rad. Tolerant - light
- High Definition measurement
- 40 MHz selective readout for hardware trigger
- Extended Pixel coverage to η ≃ 3.8

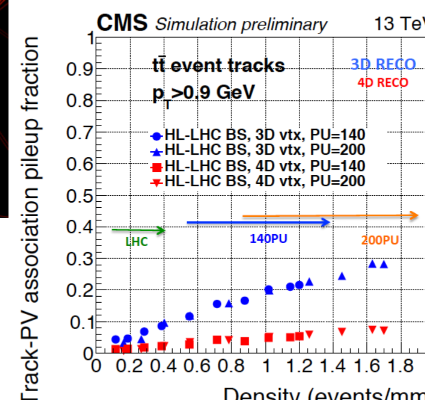
Beam radiation and luminosity
Common systems and infrastructure

MIP Precision Timing Detector



○ 200 pileup collisions





Time of flight precision ≃ 30 ps, $|\eta| < 3$, $p_T > 0.7$ GeV

"Provide a factor 4-5 effective pile-up reduction"

- ~ 15% merged vertices reduce to ≃ 1.5%
- Low pileup track purity of vertices recovered

- **All showers timed to 30 ps in calorimeters**

Bold Aspects of CMS Upgrade for HL-LHC

- Tracking information in "L1 track-trigger"
  - Tracker is designed to enable finding of all tracks with P_T>~2 GeV in under 4 μs.
- Tracker is AGAIN ALL SILICON but now with much higher granularity, and extends to $|\eta|$ =4
  - >2 billion pixels and strips
- High Granularity Endcap Calorimeters
  - Sampling of EM-showers every ~1λ_{rad} (28 samples) with small silicon pixels and then every ~0.35λ_{abs} (24 samples) with combination of silicon pixels and scintillator to map full 3-dimensional development of all showers (~6M channels in all)
- Precision timing of all objects, including single charged tracks, provides a 4th dimension to CMS object reconstruction to combat pileup (~200K sensors in barrel section)

Goal: Be as efficient, and with low background/fake-rate, at 200-250 pileup as we are today, and with extended acceptance

Summary and Outlook

Summary

- CMS data taking in 2016 was excellent
  - Both the LHC and the CMS detector performed superbly
- CMS Computing navigated the challenges of the larger than expected 2016 data set and performed very successfully in the campaign for the winter/spring conferences
- **Physics results so far have been excellent with much exciting analysis ahead**
- Installation of new devices for the 2017 run went very well
  - The Pixel Detector and HF electronics are being commissioned
- The Upgrade design is bold and exciting and is moving ahead very well toward approval in 2018

You will get much more detail on each of these topics in the course of LHCP 2017

Physics Outlook

- Now that the LHC is running at **13 TeV** with **high luminosity and availability, our discovery potential is great.**
  - Discoveries may come in a few months or after several years
  - They might start with a striking signal appearing in a single channel or they may appear as several signals emerging slowly with initially low significance out of large backgrounds from a multiplicity of hiding places.
  - They may appear in scenarios we have long been exploring, e.g. SUSY or Extra Dimensions, **or may surprise us with signatures that we are not even looking for today**
    - As investigators/ researchers into the unknown we need to step back and survey the big picture and look for new, untried approaches or unexplored corners of our data that are only dimly illuminated
- **Today we have of order <2% of the ultimate LHC data in hand**
- **It is our mission to explore and make discoveries in this huge new expanse of scientific territory**

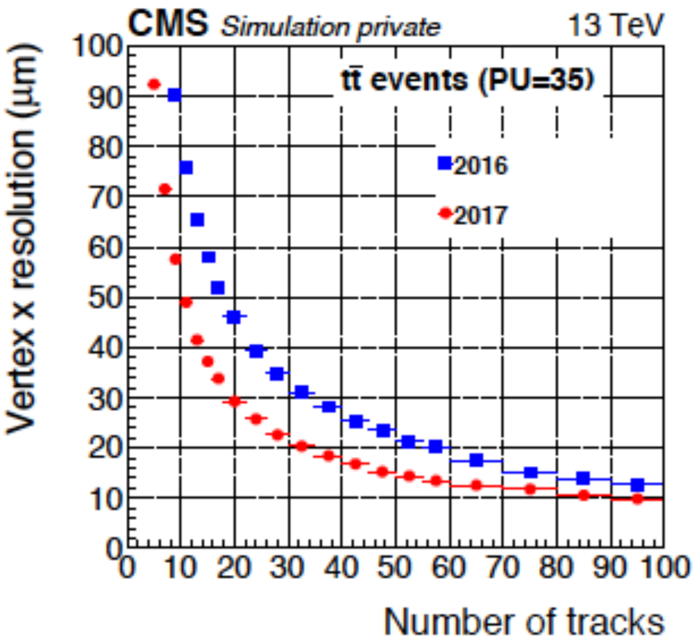
The future is bright!
Thank you for your attention.

Backup

New Results for LHCP

- HIN-16-021: Pseudorapidity distributions of charged hadrons in proton-lead collisions at 5.02 and 8.16 TeV
- SMP-16-019: Measurement of ZZ production in association with jets and search for electroweak production of two jets in association with a Z boson in proton-proton collisions at 13 TeV and 8 TeV
- SMP-17-004: Observation of electroweak production of same-sign W boson pairs in the two jet and two same-sign lepton final state at a center-of-mass energy of 13 TeV
- HIG-17-001: Search for lepton flavour violating decays of the Higgs boson to e τ and μ τ at 13 TeV
- HIG-17-005: Search for production of a Higgs boson and a single top quark in multilepton√final states
- HIG-16-040: Measurements of properties of the Higgs boson in thediphoton decay channel with the full 2016 data set
- HIG-16-043: Observation of the SM Higgs boson decaying to a pair of τ leptons at 13 TeV
- TOP-17-005: Measurement of the top quark pair-production in association with a W or Z boson at 13 TeV
- EXO-17-001: Search for light vector resonances decaying to a quark pairproduced in association with a jet
- EXO-16-004: Search for stopped long-lived particles produced in pp collisions at 13 TeV
- EXO-16-045: Search for heavy neutrinos and W bosons with right-handed couplings at 13 TeV
- EXO-16-048: Search for new physics in final states with an energetic jet,or a hadronically decaying W or Z boson with full 2016 dataset
- EXO-16-052: Search for Dark Matter, Invisible Higgs Boson Decays, and Large Extra Dimensions in the ll + Emiss final state
- EXO-16-054: Search for Dark Matter Produced in Association with aHiggs Boson Decaying to Two Photons
- B2G-17-003: Search for VLQ pair production using kinematic reconstruction in the lepton+jets final state
- B2G-17-008: Search for top quark partners with charge 5/3 in the single-lepton final state
- SUS-16-050: Search for supersymmetry using hadronic top quark tagging at 13 TeV

Expected Performance of Phase I Upgrade Pixel Reconstruction



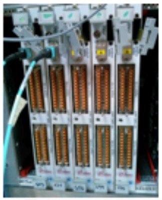
- Better resolution (20–40 %)

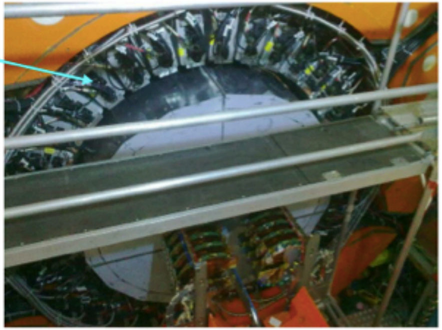
Time spent in tracking for ttbar event with pileup 35 is 10% lower per event than now.

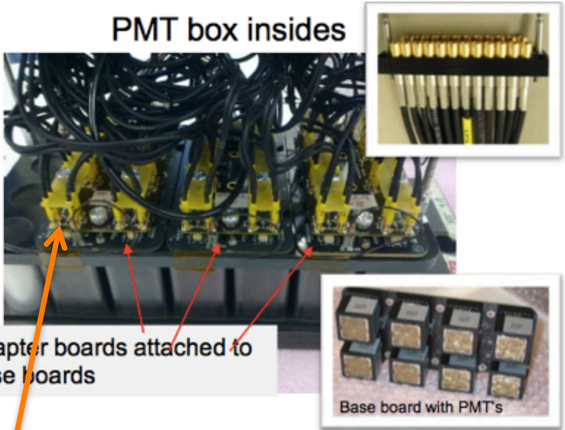
HF: Forward Hadron Calorimeter

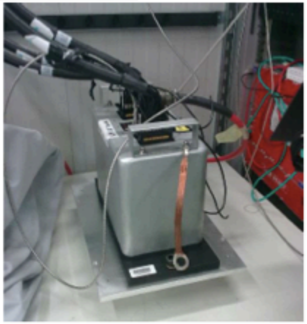
- New thin-windowed, metal envelope Multi-anode PMTs were installed in LS1
  - Less glass eliminated sources of Cerenkov light that were causing large pulses ➔ Fake MET
  - Multianode feature is the next step in this process since true signals are symmetric and false ones are not
    - Anodes currently ganged in "adapter board"
  - Timing is also different and a TDC is part of the new readout, implemented in the new QIE board
- Status (Led by University of Iowa)
  - PMT box rework started – December 7th 2016
  - PMT box rework completed – February 10th 2017
  - All PMT boxes installed – February 16th 2017 (three weeks ahead of schedule!)

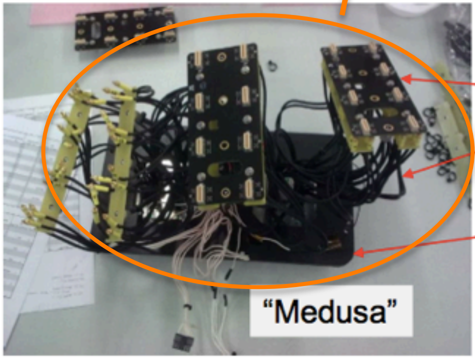
HF: 1-channel → 2-channel Readout



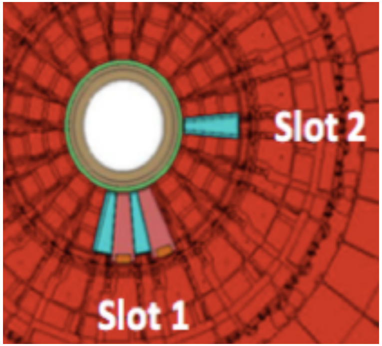


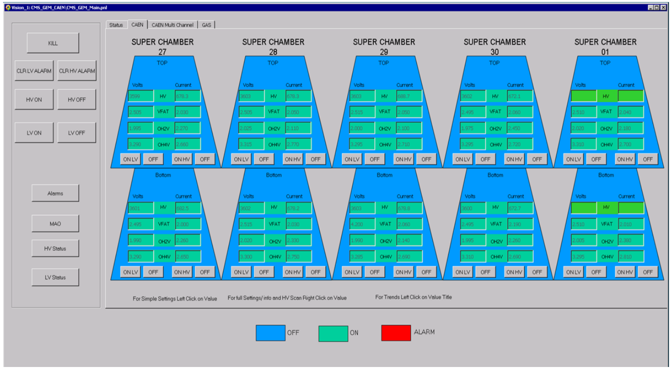




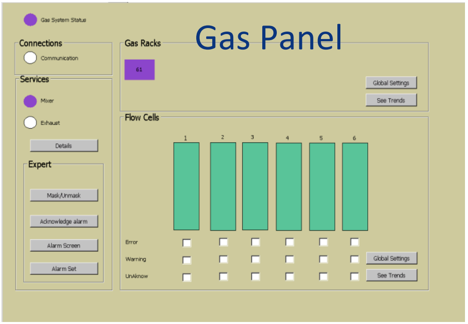


MUON GEM GE1/1 SLICE at P5





DCS operational trending: HV, I_{mon}, gas parameters continuously monitored



DCS HV and LV panel

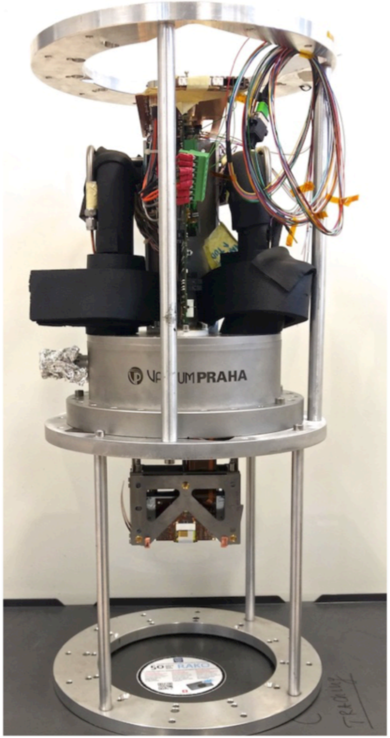
- DCS, DB work on going for monitoring
- First report in CMS Run Meeting – 14.3.2017
- DQM needs to be set up
- DPG just starting work on real data!

- Now planning for combined run with CSC for latency scan
- Then muon detection with GEM

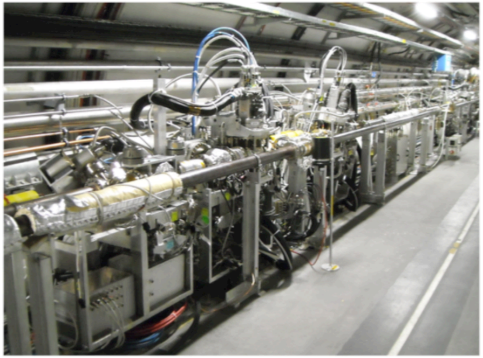
CT-PPS

- Construction and assembly of the new 3D Pixel tracking detectors (RPIX) was concluded.
  - Installation in sectors 4-5 and 5-6 is done.
- New Ultra-Fast Silicon Detectors (UFSD) have been built and added to the CT-PPS Timing stations.
- First analysis using CT-PPS data was pre-approved (proton tagged $\gamma\gamma \rightarrow \mu^+\mu^-$) using 9.2 fb^{-1} of 2016 data.

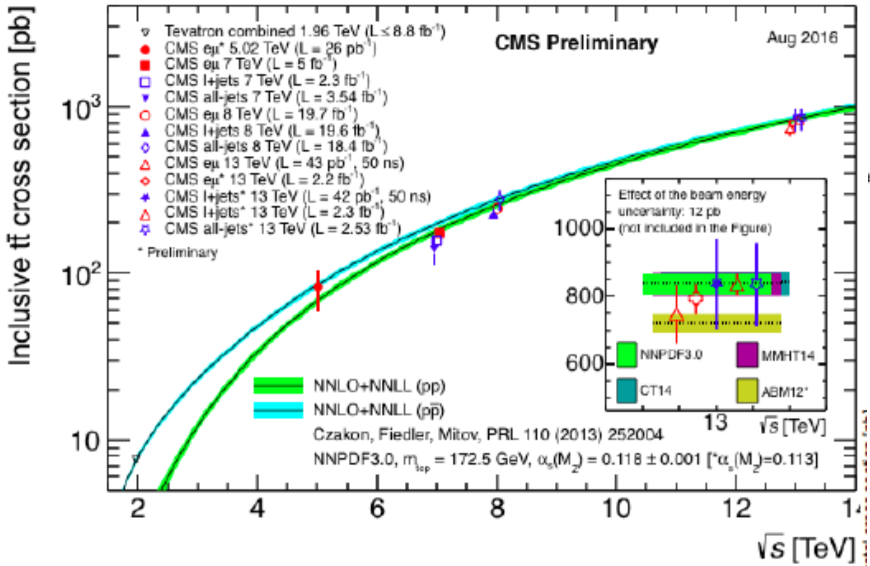
pixel detector package installed in March

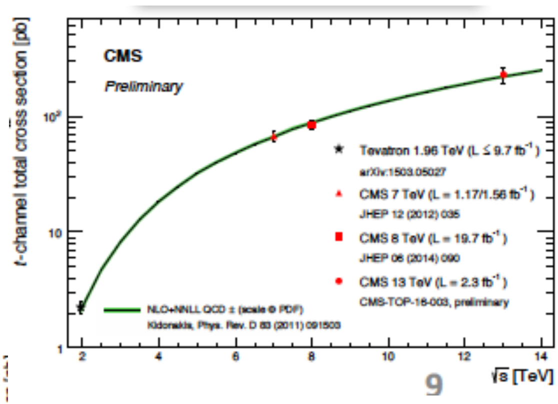


View of the tunnel in the region of the RPs



Top Cross Sections





Single Top ~1 Hz !!!

Top pair production of ~10 Hz !!!

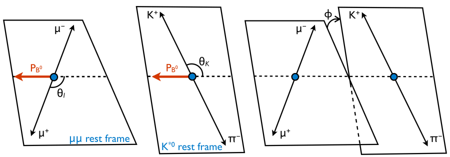
Can address new topics, e.g. CP violation and very rare decays

$K^*\mu^+\mu^-$ Backup

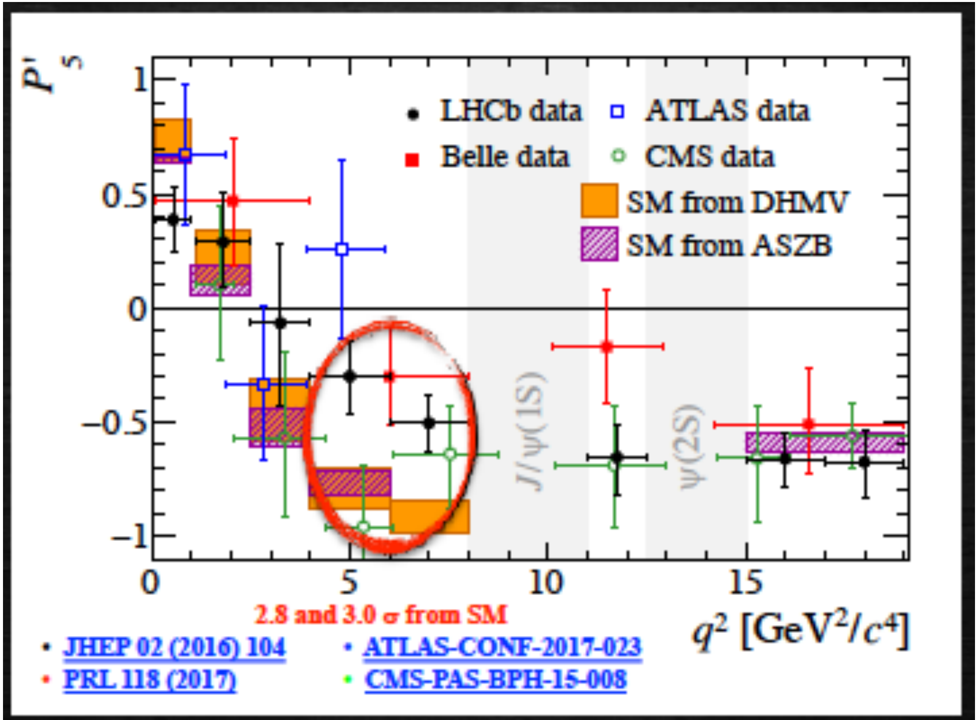
$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_K\, d\phi} = \frac{9}{8\pi}\left\{\frac{2}{3}\left[(F_S + A_S\cos\theta_K)(1-\cos^2\theta_l) + A_S^5\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right] + (1-F_S)\left[2F_L\cos^2\theta_K(1-\cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{1}{2}P_1(1-F_L)(1-\cos^2\theta_K)(1-\cos^2\theta_l)\cos 2\phi + 2P_5'\cos\theta_K\sqrt{F_L(1-F_L)}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right]\right\}. \qquad (1)$$

The expression is an exact simplification of the full angular distribution, obtained by folding the ϕ and θ_l angles around zero and $\pi/2$, respectively. Specifically, if $\phi < 0$, then $\phi \to -\phi$, and the new ϕ domain is $[0, \pi]$. If $\theta_l > \pi/2$, then $\theta_l \to \pi - \theta_l$, and the new θ_l domain is $[0, \pi/2]$. Fitting the data with the full angular distribution would cause fit convergence problems due to the limited number of signal candidate events, which is why we adopt the folding procedure. It exploits the odd symmetry of the angular variables with respect to $\phi = 0$ and $\theta_l = \pi/2$ in such a manner that the cancellation about these angular values is exact.

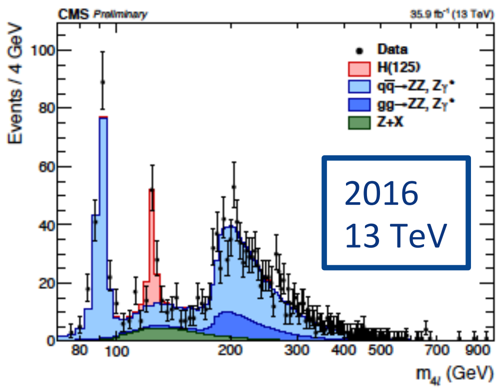
P5′ in $B^0 \to K^{*0}\mu^+\mu^-$

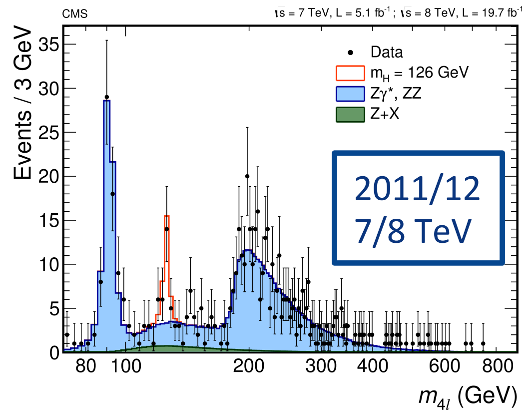


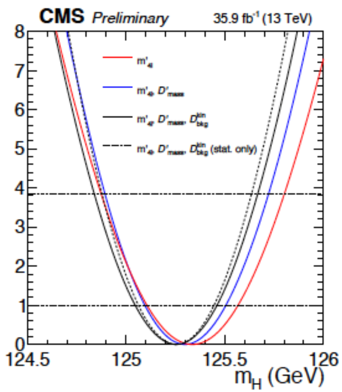
Summary from CERN Seminar by Simone Bifani (LHCb), April 18, 2017



Higgs Mass from 4 Leptons (ZZ*)





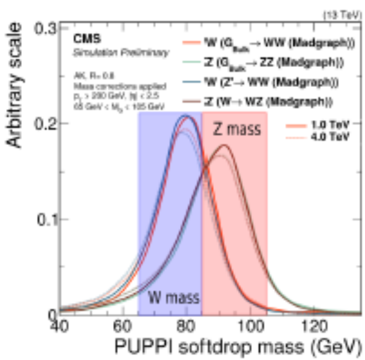


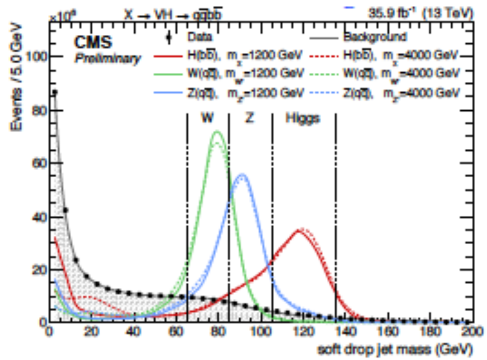
Mass (2016, 4L) : $125.26 \pm 0.20(stat) \pm 0.08(sys) Gev$

ATLAS + CMS:
Mass (Run 1, all): $125.09 \pm 0.21(stat) \pm 0.11(sys) Gev$

Best single measurement of Higgs mass!
Better than all modes, ATLAS and CMS from Run1!

Di-Boson Searches

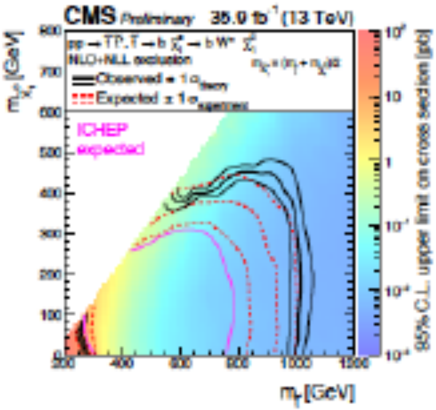


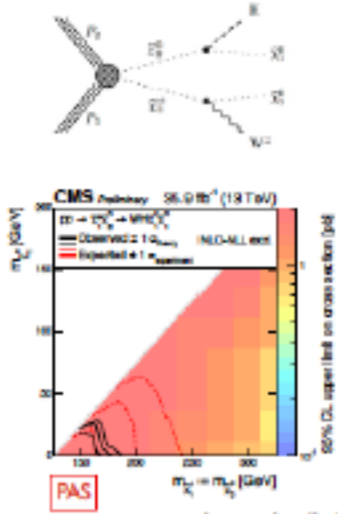


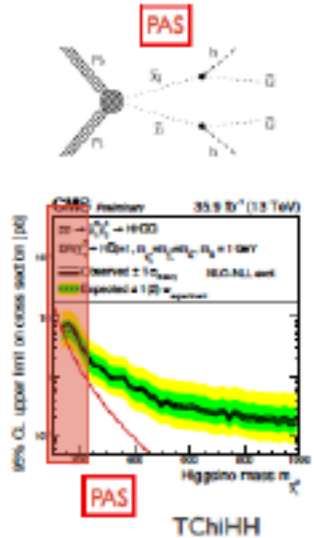
Channel	V= W/Z Final states						
γγ	γγ						
Vγ	llγ	lνγ	qqγ				
VV	4l	llνν	llqq	lνqq	ννqq	4q	
VH	llbb	lνbb	ννbb	qqbb	lνττ	llττ	qqττ
qV	qqq						

- Boosted topologies now used as standard tools for V-tagging and also Higgs-tagging
- new results presented for VV, VH and HH
- No new excess and no confirmation of old minor excesses

SUSY Campaign

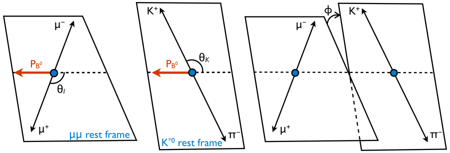


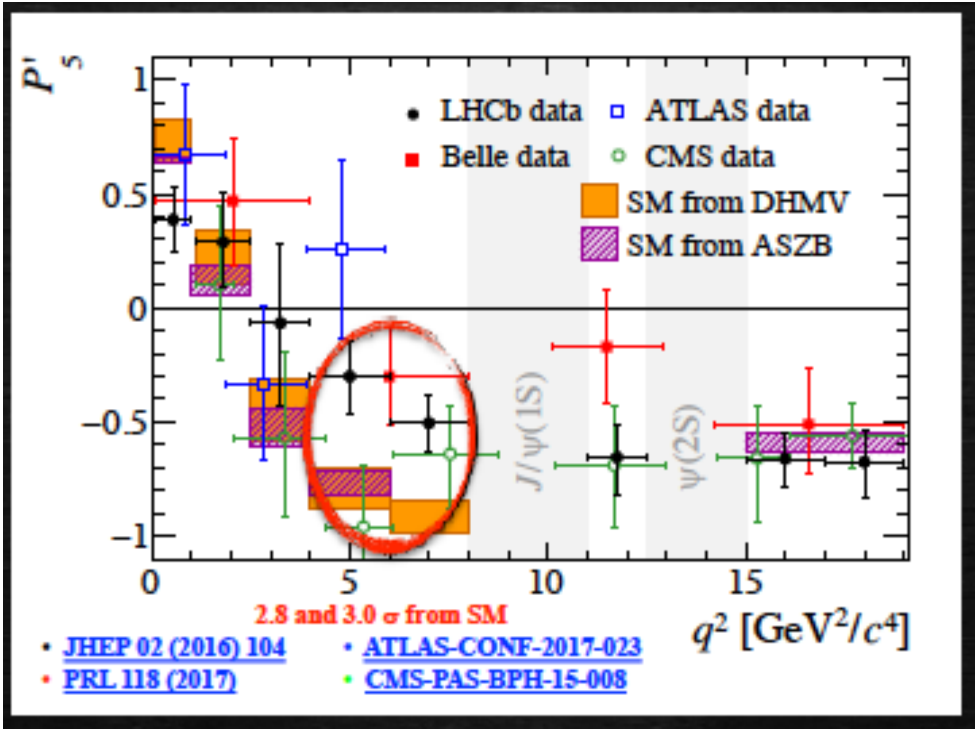




- 17 new results using full 2016 data. 12 are already in CWR.
- Very few mild excesses in hundreds of signal regions
- Updated and most stringent constraints on EWK-inos
- Higgs tagging is now also part of the SUSY program
- Higgsinos are the next focus of SUSY searches with the increased statistics

P5′ in $B^0 \rightarrow K^{*0}\mu^+\mu^-$

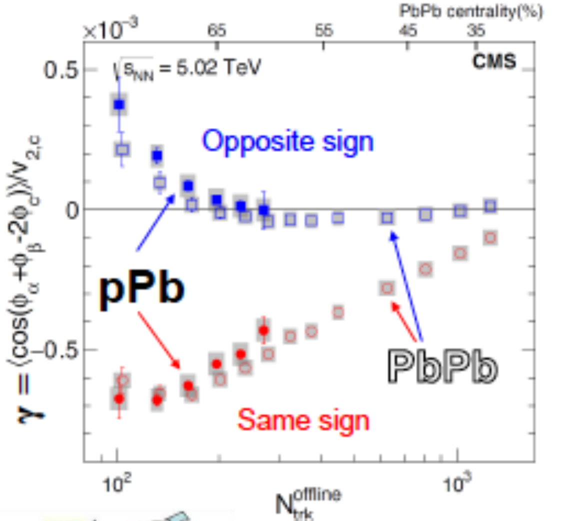




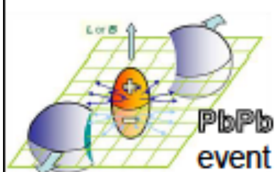
Summary from CERN Seminar by Simone Bifani (LHCb), April 18, 2017

Highlights from Heavy Ion Physics

Charge Separation Signal γ

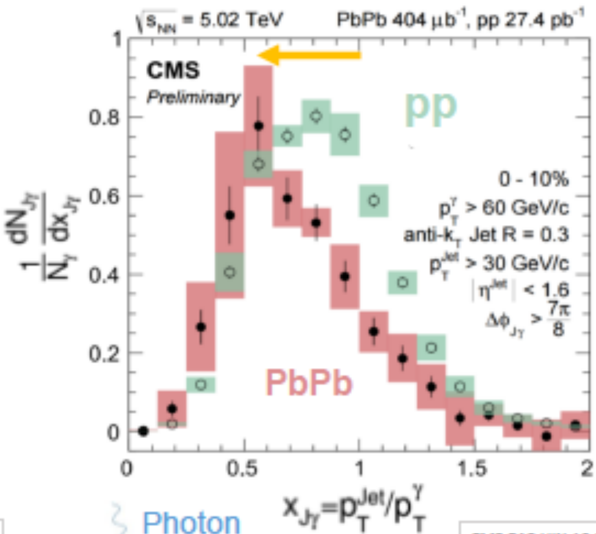


arXiv: 1610.00263
PRL 118, 122301 (2017)

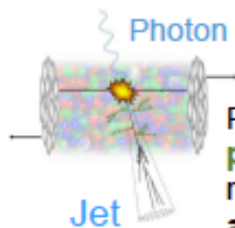


PbPb and **pPb** with the same event multiplicity are **similar!** Challenge to Chiral Magnetic Effect interpretation!

Photon-Jet



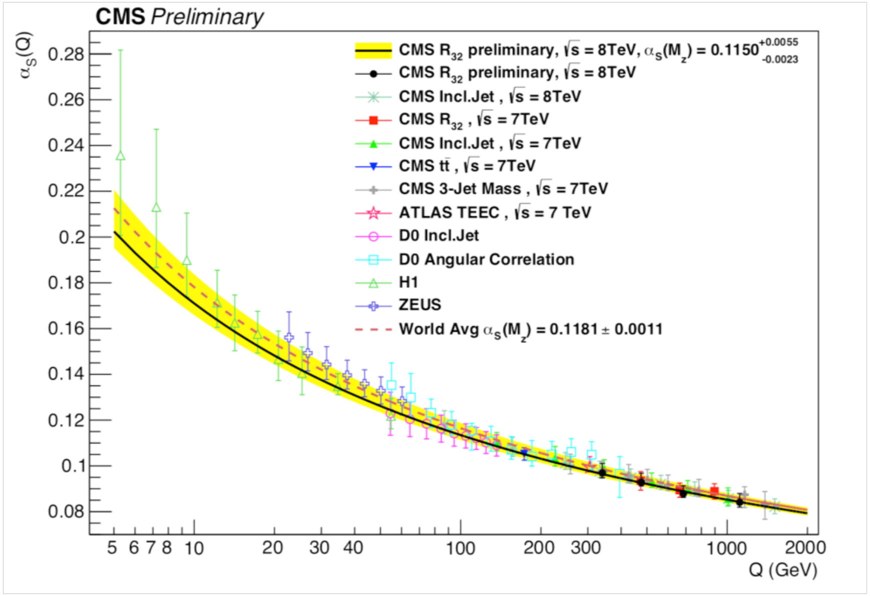
CMS-PAS-HIN-16-002



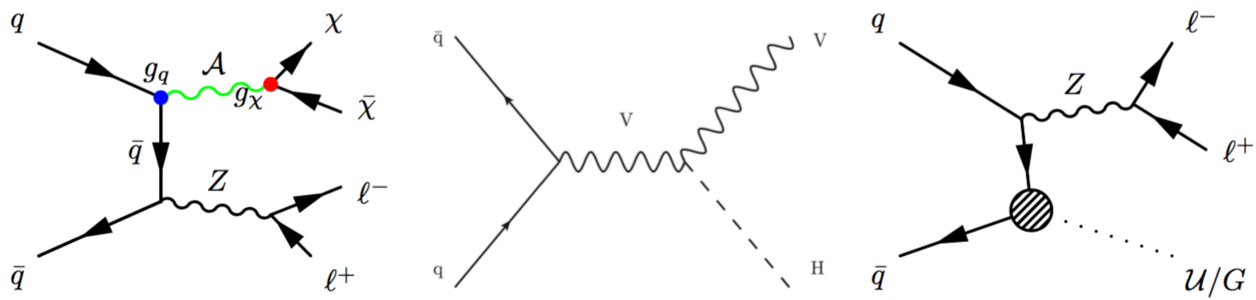
Photon-Jet correlation in pp and PbPb: high precision measurement of in-medium **absolute parton energy loss**

α_s Measurement

Most recent results based on 2,3 Jet events and their ratio, $R_{32} = \sigma_{3\text{-jet}}/\sigma_{2\text{-jet}}$.



Z + MET

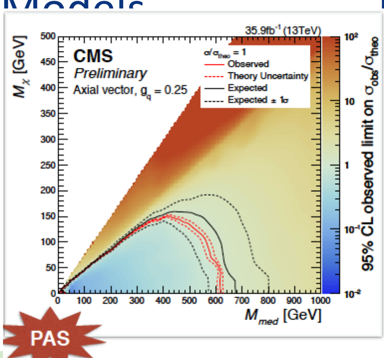


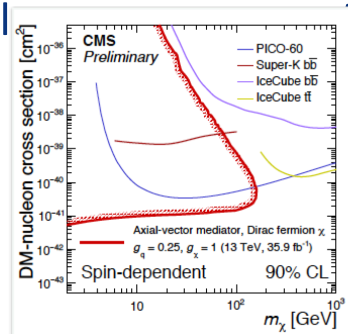
(a) (b) (c)

DM Models

Higgs Invisibl

ADD





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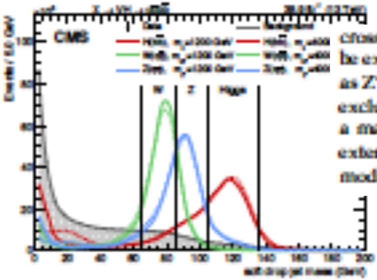


cross section. With the current data set, a narrow W′ resonance with $m_{W'} \lesssim 3.27$ (3.10 TeV) can be excluded at 95% CL, except in a limited region between 2.54–2.76 TeV (2.46–2.82 TeV), as well as Z′ resonance with $m_{Z'} \lesssim 2.41$ (2.31 TeV) in the HVT model B $g_V = 3$ (model A $g_V = 1$). The exclusion limits for the heavy vector triplet hypothesis are also presented in Fig. 6, excluding a mass range from 1.00–2.66 and 2.72–3.39 TeV in the benchmark model B and significantly extending the reach with respect to the $\sqrt{s} = 8$ TeV and $\sqrt{s} = 13$ TeV CMS searches [19, 22]. In model A, the excluded range is between 1.00–2.51 TeV and 2.80–3.26 TeV.

Figure 1: Distribution of the soft drop PUPPI mass for data, simulated background, and signal. The distributions are normalized to the number of events observed in data. The dashed vertical lines represent the boundary values of the jet mass categories.

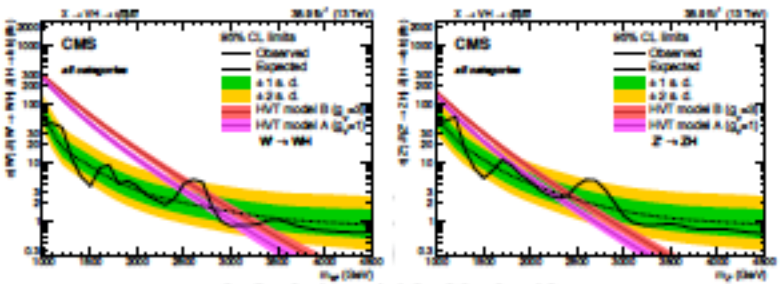
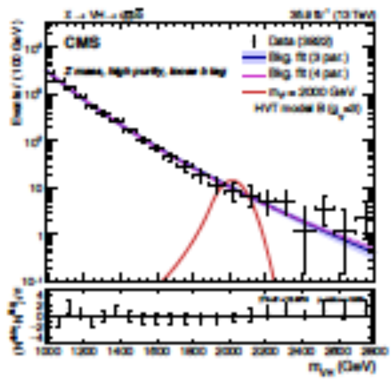
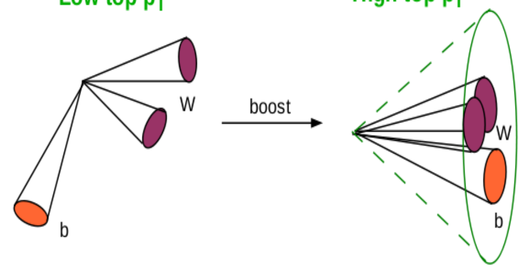


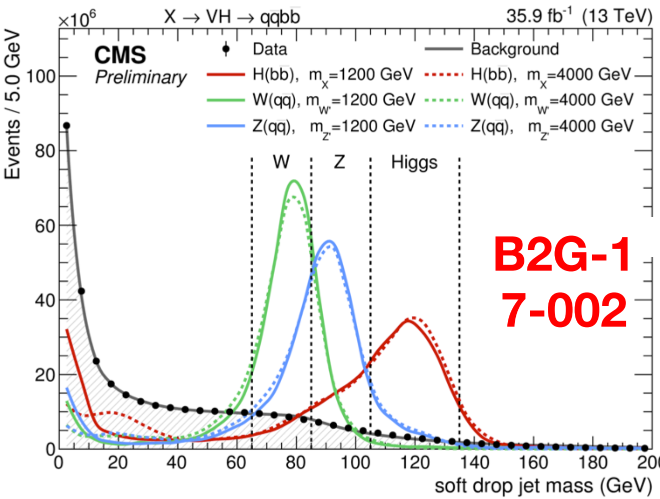
Figure 5: Observed and expected 95% CL upper limits on $\sigma(W')\mathcal{B}(W' \to WH)\mathcal{B}(H \to b\bar{b})$ (left) and $\sigma(Z')\mathcal{B}(Z' \to ZH)\mathcal{B}(H \to b\bar{b})$ (right) as a function of the resonance mass for a single narrow spin-1 resonance, including all statistical and systematic uncertainties. The inner green and outer yellow bands represent the ±1 and ±2 standard deviation uncertainties on the expected limit. The red and purple solid curves correspond to the cross sections predicted by the HVT model B ($g_V = 3$) and model A ($g_V = 1$), respectively.



Boosted signatures from jet substructure

- **Very active field: lots of ideas, variables, methods**
- **~~Basic strategy (oversimplifying):~~**
  - **a) use wide jets to start with (typical radius in jet algorithms): ~ 0.8 - 1.0**
  - **b) “drop” soft/far activity to better disentangle the core of individual particles (“grooming”)**
  - **c) Test best consistency with a 1, 2, …, N jet structure (“sub-jetiness”, D_2)**





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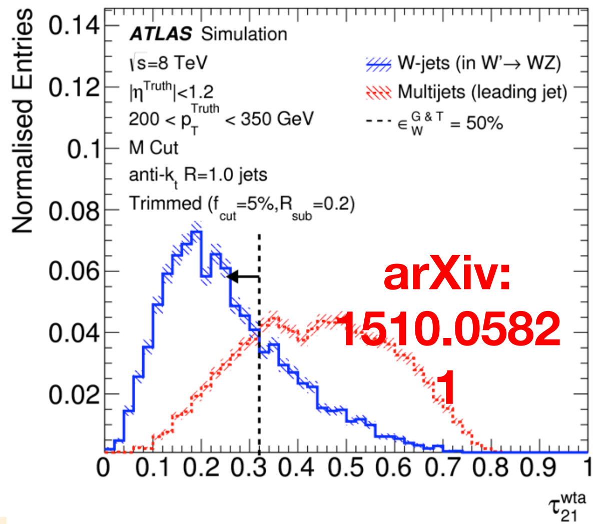
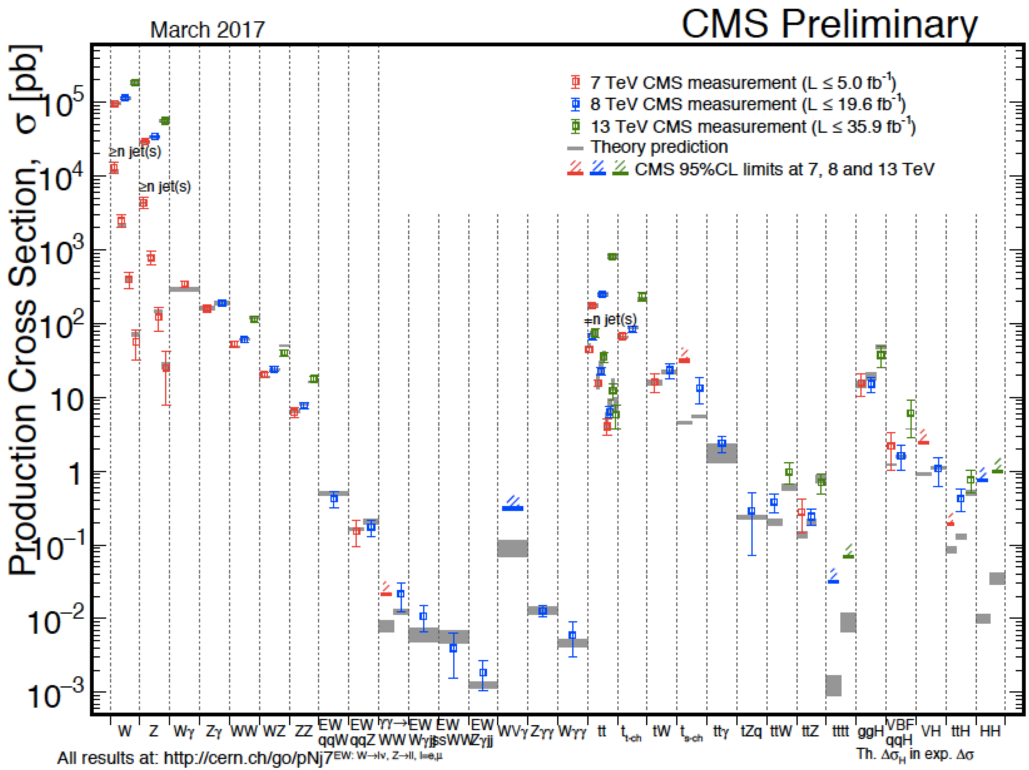
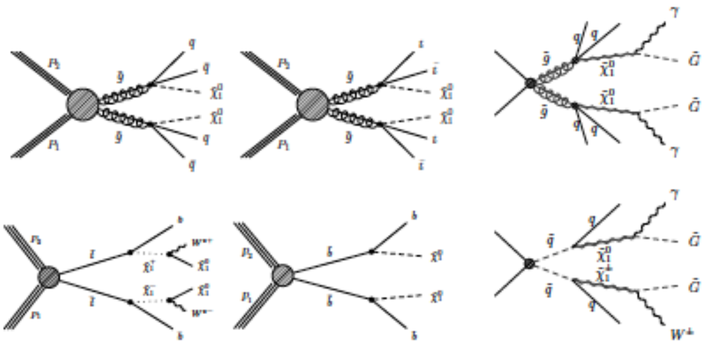


arXiv: 1510.05821

Production Cross Sections

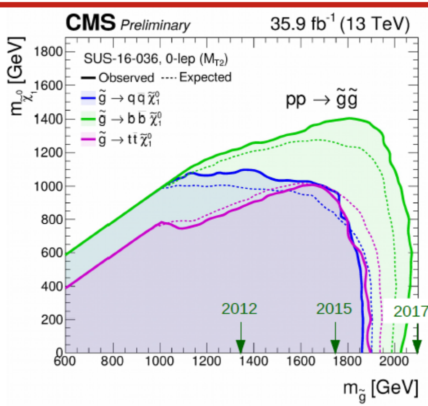


Strong SUSY



The SUSY particles produced have color (gluinos, squarks). Typical searches look for jets + missing E_t, with or without other objects.

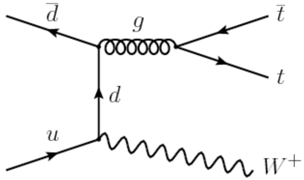
Limits have reached 2 TeV



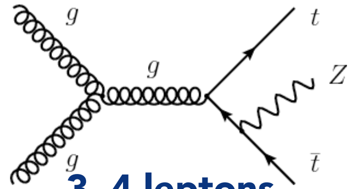
Recent CMS Strong SUSY studies (~18 Public Conf Notes)

- All-hadronic + MET
- 1 lepton + MET
- 2 opposite sign leptons + MET
- 2 same sign leptons or ≥3 leptons + MET
- Photon(s) + MET

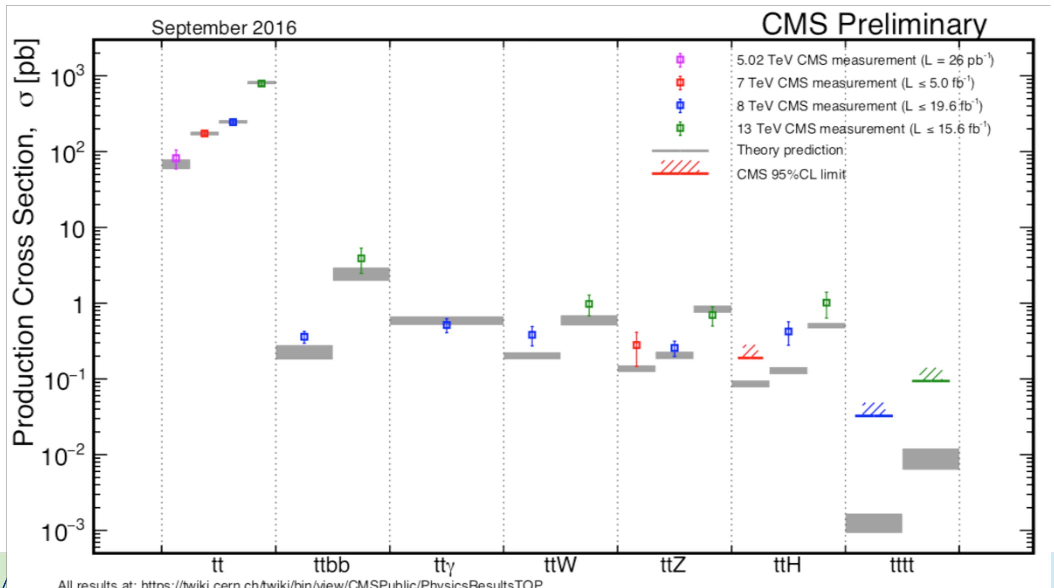
Top Production with additional objects – ttW and ttZ



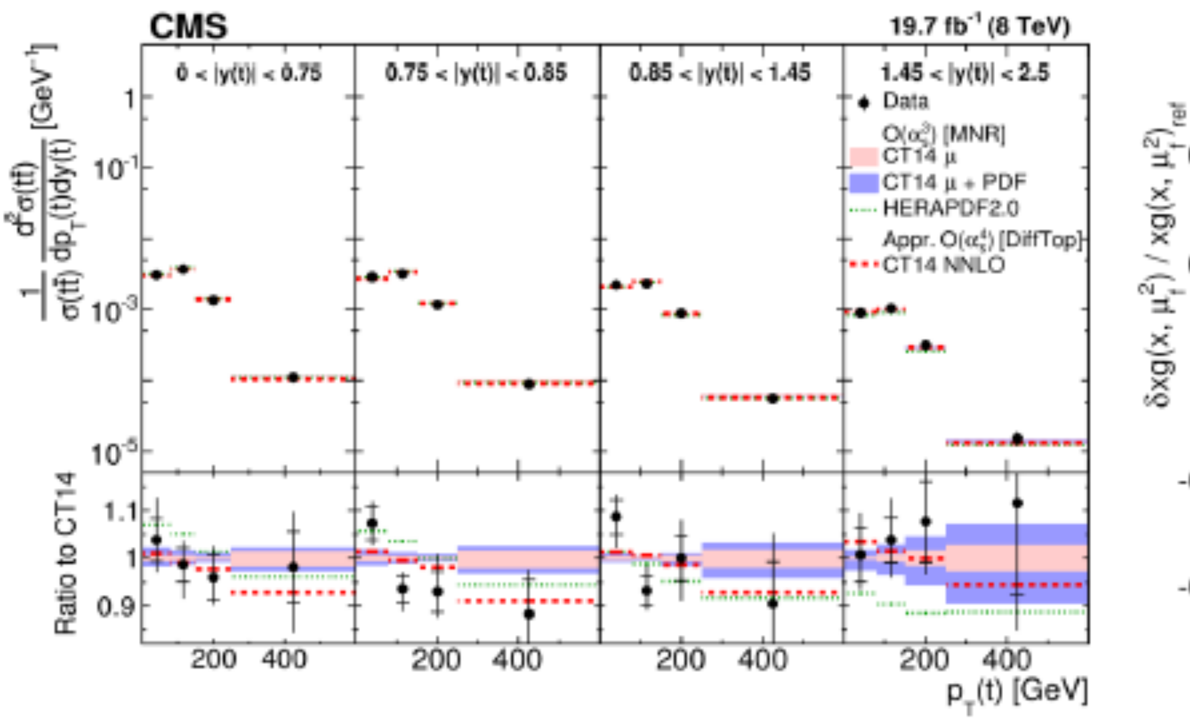
Same sign di-lepton



3, 4 leptons



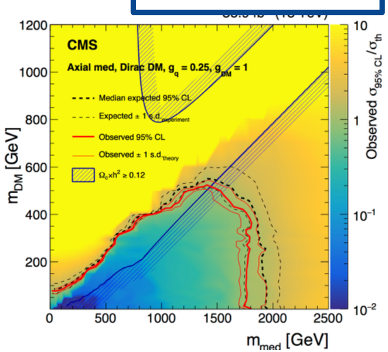
Top P_T distribution agrees with NNLO

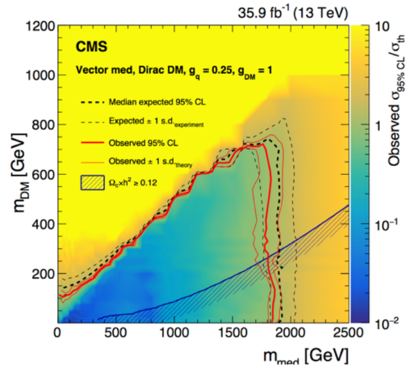


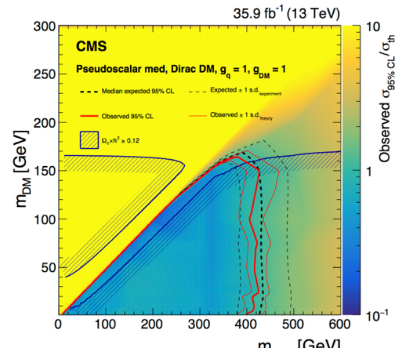
Dark Matter

Mono-jet and mono-V search with full 2016 dataset. Limits on Simplified models of DM and several other topics. No useful exclusion area for scalar mediator.

EXO-16-004







PAS